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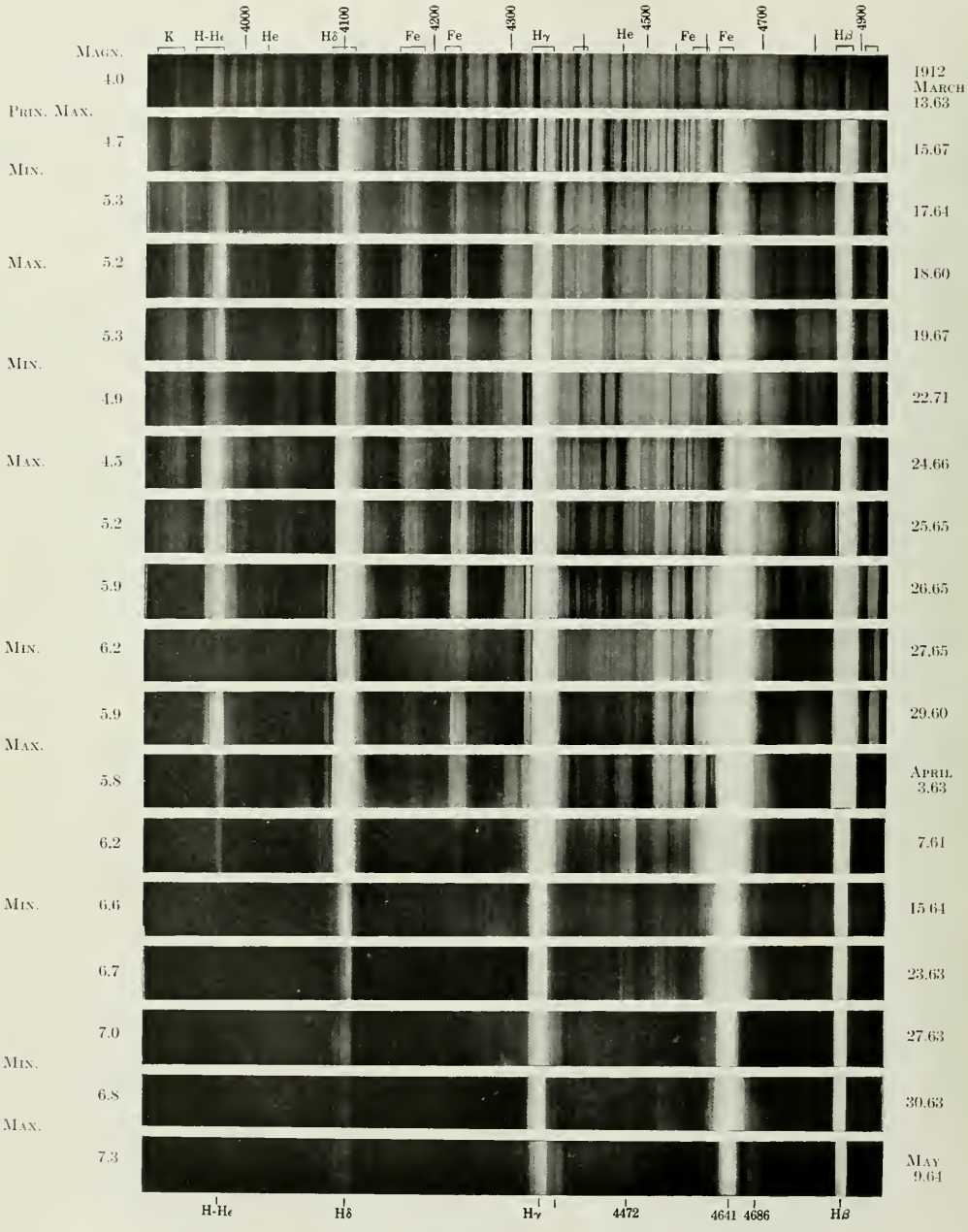

Plate A. Spectra of Nova Geminorum II

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Astron
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DETROIT OBSERVATORY

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OF THE

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OF THE

UNIVERSITY OF MICHIGAN

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WIDTHS OF HYDROGEN AND METALLIC EMISSION LINES IN CLASS B STELLAR SPECTRA

STUDIES OF CLASS B STELLAR SPECTRA CONTAINING EMISSION LINES FIFTH PAPER[1]

By RALPH H. CURTISS

The widths of absorption or emission lines in any spectrum constitute evidence bearing strongly on the physical condition of the source of radiation. Such evidence when available for lines of different wave-lengths in a number of similar sources under investigation spectroscopically is of especial value. In the study of stellar conditions, qualitative spectral line widths have pointed to useful conclusions with reference to density, pressure, convection currents, and rotation of atmospheric envelopes. Quantitative results, where available, will be still more valuable in this connection, particularly in combination with appropriate laboratory research.

The present paper describes a quantitative investigation of the line widths of the emission components of certain hydrogen and metallic lines in twelve Class Bp stellar spectra. The outer edges of the emission components of the lines in the Huggins series of hydrogen, flanked as they are by absorption, present fairly sharp features for measurement with single prism dispersion. Good determinations of the width of such lines are possible. In addition, useful though less reliable measures of the width of metallic emission lines in these spectra can be made.

DEFINITION OF LINE WIDTH

The width of any object on a photograph requires definition and such definition should depend on the character of the object involved. The hydrogen emission lines in many Class B spectra have relatively flat maxima, except for the central reversal, with sharp gradients on each edge where the emission gives way suddenly to absorption. Since these gradients are narrow, even under working conditions with relatively wide slits, they must be sharp features in spectra ideally pure. The center of such a gradient and not the farthest traceable limit of emission is the feature adopted as the edge of any emission line, in an attempt to reduce to a minimum the uncertainties in measured line widths due to such variables as slit width, diffraction, aberration and photographic density. Hence in the present paper the width of any emission line is taken as the difference in wave-length between the centers of the density gradients which stand out sharply at the edges of such a line under exposures timed to bring out clearly the features involved.

FACTORS TENDING TO MODIFY MEASURED LINE WIDTHS

The relation between slit width and line width is an important one in this connection. For monochromatic emission lines, under our working conditions with single-prism dispersion, the width increases nearly directly with the slit opening. However, for a line having a flat maximum with sharp gradients at the edges, the effect of increased slit width is to decrease the sharpness but not to change by important amounts the positions of the centers of such gradients if the angular width of the slit is less than the angular width of the maximum. If the width of any line be defined, as in this study, as the distance in angstroms between the centers of the edge gradients, such widths are largely, if not quite, independent of reasonable variations in slit width unless the latter is greater than the limit mentioned

[1]This paper is a continuation of the studies of Class B stellar spectra containing emission lines, begun in 1906 with an investigation of the spectrum and radial velocity of Beta Lyræ. The first of these studies is found in the *Publications of the Allegheny Observatory*. Subsequent contributions are found in the present *Publications*.

above. Of the stars studied below, only 11 Camelopardalis has lines narrow enough to require correction for slit width. Possibly all of the line widths for this star need correction. Certainly this is true of the Hβ line, which is probably nearly monochromatic, and, since the correction for slit width cannot be determined at present, the results for this line are included only in part in the discussion.

Spherical and chromatic aberration and diffraction at the camera lens are agencies which extend the extreme limits of emission lines though in much smaller degree than slit width in the present case. Like increase in slit width they reduce the sharpness of the gradients at the edges of the lines studied here but do not displace the centers of such gradients by important amounts.

Variations in effective exposure introduce in the apparent widths of spectral lines effects difficult of control. On plates stronger or weaker than one of normal exposure, the object in the measures should be to set the thread on the centers of the gradients which stand out sharply on the edges of the emission lines on well timed negatives. Difficulties clearly beset such measures, and in this as in any method of measuring line widths on a photographic plate it cannot be asserted confidently that all exposure effects can be eliminated. That they are essentially negligible in the present case has been brought out by studying the residuals from the mean for each line on different plates of each star to detect any such dependence on over- or underexposure.

If any effects due to slit width, aberration, diffraction, and exposure time remain in the measured widths of the emission lines given below, they influence in some degree the inclinations and positions of the straight lines in the accompanying figure, but not in an important way the relations brought out. Such effects, if present, are undoubtedly small. Certainly it would be difficult to find other wide lines in stellar spectra capable of yielding results as satisfactory quantitatively as those obtainable from the features studied here.

THE DATA

The detailed results of line widths in angstroms are given for each measured line on 182 spectrograms of eleven stars in Table 1. Data for a twelfth star, Kappa Draconis, are taken from a paper by Professor R. H. Baker in this series. For each star the plate numbers and dates are given, followed by the line widths in angstroms and the corresponding weights, beginning with Hβ and running up to the last hydrogen line visible in all spectra except those of Gamma Cassiopeiæ and Beta Monocerotis, where the proximity of the H line of calcium impaired the value of the measures of Hε. This latter line was therefore omitted in these two cases. For f^1 Cygni, H. R. 985, and Gamma Cassiopeiæ, measures of emission lines have been published in previous papers. Such measures are repeated here in order to make the present table complete to date. For the first two of these stars the line widths, which in previous papers were derived on a different basis from that of the present table, are here made homogeneous with the rest.

Also in Table 1, line widths of metallic emission lines are given for all stars in whose spectra these features were measurable. For such the columns are headed by numerical wave-lengths. In every case the source of the line is iron. Such measures are usually much inferior in accuracy to those of the hydrogen lines. In the metallic lines the structure was not so clearly shown. But the results are of importance so far as they go.

The right ascensions and declinations of the stars in this table are for the epoch 1900.0. The widths of emission lines are expressed in angstroms.

TABLE I

WIDTHS OF EMISSION LINES IN CLASS B SPECTRA

H. R. 264. γ 27 CASSIOPEIÆ

R.A. $0^h\ 50^m.7$; Decl. $+60°\ 11'$

Class, Bp. Magnitude, 2.25

PLATE NO.	GR. M. T.		WIDTHS OF EMISSION LINES						
			Hβ	Hγ	Hδ	Hζ	λ4584	λ4385	λ4233
134	1911 July	17.90	5.56 (1)	4.31 (1)	4.01 (½)				
197	Aug.	30.81	5.83 (1)	4.31 (1)	3.92 (1)				
198		30.83	5.48 (1)	4.46 (1)	3.99 (1)		5.55 (1)		
199		30.84	5.18 (2)	4.84 (2)			5.78 (1)		
200		30.86	5.03 (1)	4.01 (1)	3.89 (1)		5.55 (1)		4.04 (½)
210	Sept.	19.80	5.12 (1)	4.29 (½)					
211		19.80	5.24 (1)	4.05 (1)	3.95 (½)				
212		19.81	4.77 (1)	4.18 (1)	3.71 (1)		5.71 (½)		
214		22.84	4.29 (1)	4.10 (1)	3.86 (1)		5.05 (1)		
215		22.85	4.77 (1)	4.24 (1)	3.80 (½)				
221		23.82	4.85 (1)	4.31 (1)	4.07 (1)		4.20 (½)	4.20 (½)	
222		23.83	5.51 (1)	4.41 (½)	4.31 (½)				
229		27.81	4.71 (1)	4.07 (1)					
230		27.82	4.71 (1)	4.31 (1)					
235	Oct.	2.76	4.94 (½)	4.01 (1)					
236		2.77	4.65 (½)	4.14 (1)					4.00 (½)
241		7.78	4.94 (1)	4.01 (1)					
242		7.79	4.50 (1)	4.31 (1)	4.01 (½)			5.00 (½)	
246		11.76	5.36 (1)	4.14 (½)	4.25 (½)				
247		11.77	5.27 (1)	4.45 (1)	3.96 (½)				
254		13.66	5.21 (1)	4.48 (1)					
255		13.68	5.62 (1)						
264		18.76	5.00 (1)	4.37 (½)	3.38 (1)		4.79 (½)		
265		18.77	5.36 (1)	4.64 (1)	4.38 (½)			4.79 (½)	
282		27.73	5.48 (1)	4.28 (1)	3.98 (1)				
283		27.73	5.15 (1)	4.31 (1)	4.02 (½)				
1108	1912 Sept.	26.79	5.03 (1)	4.31 (½)			3.72 (½)		
1447	Nov.	10.73	5.03 (½)						
1448		10.75	5.33 (1)	4.33 (½)	3.99 (½)				
1507		27.64	5.33 (½)	4.18 (1)	3.80 (½)				
1508		27.65	5.62 (½)						
1530		30.62	4.71 (1)	4.37 (1)	3.89 (½)				
1531		30.63	4.47 (1)	4.54 (1)	4.51 (1)		5.78 (1)		4.70 (½)
1537	Dec.	4.66	4.88 (1)	4.79 (1)	3.81 (½)				
1538		4.67	4.88 (1)	4.48 (1)	4.01 (½)				
1540	1912 Dec.	7.55	4.97 (1)	4.24 (½)	3.78 (½)		5.31 (½)		
1541		7.56	5.36 (½)	4.65 (1)					
1544		8.59	5.06 (1)	4.37 (1)	4.05 (1)		5.36 (½)		
1545		8.62	5.39 (1)	4.07 (1)					
1550		11.66	4.68 (1)	4.05 (1)	3.87 (½)		4.74 (1)		4.27 (½)

H. R. 264. γ 27 CASSIOPEIÆ — Continued

R.A. $0^h\ 50^m.7$; Decl. + 60° 11′

Class Bp. Magnitude, 2.25

PLATE NO.	GR. M. T.		WIDTHS OF EMISSION LINES						
			Hβ	Hγ	Hδ	Hζ	λ4584	λ4385	λ4233
1552	1912 Dec.	14.61	5.12 (1)	4.56 (1)	3.93 (1)				
1553		14.62	4.88 (1)	4.75 (1)	3.95 (½)				
1564		22.60	4.65 (2)	4.65 (2)			5.62 (½)		
1565		22.61	5.00 (1)	4.16 (1)					
1572	1913 Jan.	12.60	4.85 (1)	4.46 (1)			5.69 (½)	4.39 (½)	
1573		12.62	4.56 (1)	4.71 (1)	4.08 (1)		4.93 (½)		
1574		12.63	5.12 (1)	4.20 (1)			5.17 (½)		3.57 (½)
1600	Feb.	8.59	5.62 (1)	4.39 (1)	4.51 (1)		5.73 (½)		
1601		8.60	4.44 (½)	4.16 (1)			5.64 (½)		
2244	Aug.	24.83	5.42 (1)	4.64 (1)	3.53 (½)				
2245		24.84	4.53 (1)	4.41 (1)			5.14 (½)		
2351	Oct.	4.70	5.24 (1)	4.52 (½)					
2352		4.71	4.82 (1)	4.41 (1)	4.02 (½)				
2362		9.67	4.77 (1)	4.26 (½)					
2363		9.69	5.33 (1)	4.43 (1)	3.68 (1)				3.52 (½)
2378		12.72	4.85 (1)	4.39 (1)	4.01 (1)				
2379		12.74	4.71 (1)	4.50 (1)	4.19 (½)				
2394		18.68	4.56 (1)	4.62 (1)					
2395		18.70	5.56 (1)	4.00 (1)					
2396		18.76	4.71 (1)	4.62 (1)					
2402		25.72	5.27 (1)						
2403		25.74	5.42 (1)	4.16 (1)	3.86 (1)				
2414	Nov.	1.68	5.74 (1)	4.64 (1)	3.56 (½)				
2415		1.70	4.56 (1)	4.09 (1)					
2524	Dec.	27.60	4.68 (1)	4.48 (1)	4.02 (1)		5.66 (½)		4.36 (½)
2525		27.62	5.48 (1)	4.12 (1)	3.62 (1)		5.07 (1)		
2530	1914 Jan.	1.56	4.94 (1)	4.62 (1)	3.68 (½)		5.43 (½)		3.56 (½)
2564	Feb.	5.60	5.03 (1)	4.35 (1)					
2583		19.57	5.42 (1)		3.75 (½)	3.72 (½)			
2584		19.58	4.82 (½)	4.38 (1)	3.64 (1)		5.31 (½)	3.62 (½)	3.40 (½)
3039	Oct.	24.73	5.21 (1)						
3077	Dec.	31.60	4.77 (½)	4.04 (½)	4.24 (1)	4.12 (½)			
3078		31.68	5.68 (1)	4.52 (1)	3.66 (1)	3.67 (1)		4.60 (½)	4.75 (½)
		Means.	5.06 (70)	4.38 (64)	3.94 (32)	3.79 (2)	5.28 (15)	4.43 (3)	4.03 (5)

H. R. 496. φ 54 PERSEI

R.A. $1^h\ 37^m.4$; Decl. $+5c^\circ\ 11'$

Class, Bp. Magnitude, 4.10

PLATE NO.	GR. M. T.	WIDTHS OF EMISSION LINES						
		Hβ	Hγ	Hδ	λ4630	λ4584	λ4352	λ4233
269	1911 Oct. 22.70	6.87 (3)	5.47 (3)	5.30 (1)	5.51 (1)		5.06 (1)	4.83 (1)
274	23.69	6.63 (3)	5.47 (3)	4.92 (1)			5.04 (1)	
275	23.73	6.66 (3)	5.47 (2)		6.59 (1)	5.31 (1)		
290	Nov. 22.67	6.96 (3)	5.68 (3)	5.23 (1)	6.69 (2)			
292	29.65	7.02 (3)	5.80 (2)	5.02 (1)	6.30 (1)	6.42 (1)		
293	29.69	7.31 (3)	5.07 (2)	5.31 (1)	5.68 (1)	5.90 (1)		
308	Dec. 5.78	7.02 (3)	5.93 (2)	5.27 (2)	5.88 (1)	6.35 (1)		
1227	1912 Oct. 12.71	7.22 (3)	5.80 (3)	5.17 (2)	6.20 (1)		5.79 (1)	5.52 (1)
1231	13.67	6.81 (3)	5.70 (2)	4.99 (2)				
1232	13.69	7.31 (3)	5.70 (2)	5.00 (2)				
	Means,	6.98 (30)	5.61 (24)	5.13 (13)	6.19 (8)	6.00 (4)	5.30 (3)	5.18 (2)

H. R. 985. — CAMELOPARDALIS

R. A. $3^h\ 11^m.2$; Decl. $+65^\circ\ 17'$

Class, B2p. Magnitude, 4.76

PLATE NO.	GR. M. T.	WIDTHS OF EMISSION LINES		
		Hβ	Hγ	Hδ
1360	1912 Oct. 26.76	6.54 (1)		
1404	Nov. 3.75	6.63 (1)	5.34 (1)	
1449	10.77	6.81 (1)	4.81 (½)	
1477	19.71	6.75 (1)	5.32 (½)	
1504	22.78	6.39 (1)	5.40 (½)	5.24 (½)
1509	27.68		4.81 (½)	4.92 (½)
1532	30.66	6.75 (½)		
1539	Dec. 4.70	6.39 (½)		
1554	14.63	6.36 (1)	5.04 (½)	
3429	1916 Jan. 22.67	6.90 (1)		
3430	22.73	6.81 (1)		
3436	Feb. 29.60	6.91 (1)	6.44 (0)	
3437	29.63	6.48 (1)	5.53 (½)	
3450	Mar. 15.60	6.54 (½)		
3454	16.64	7.10 (1)	5.42 (½)	
3461	23.62	6.45 (½)	5.32 (½)	
3463	30.64	6.48 (1)		
3470	Apr. 6.58	6.90 (1)	6.25 (½)	4.38 (1)
3471	6.62	6.28 (1)		
3494	17.60		5.05 (½)	
	Means,	6.65 (16)	5.30 (6)	4.73 (2)

H. R. 1087. ψ 37 PERSEI

R.A. $3^h\ 29^m.4$; Decl. $+47°\ 51'$

Class, B5p. Magnitude, 4.26

PLATE NO.	GR. M. T.	WIDTHS OF EMISSION LINES Hβ	Hγ	Hδ	λ4630	λ4584	λ4233
237	1911 Oct. 2.82	5.45 (3)	5.13 (3)	4.53 (1)		5.31 (1)	
256	13.72	6.01 (3)	4.86 (2)	4.54 (2)			
266	18.79	5.95 (3)	4.77 (3)	4.77 (1)		6.04 (1)	
270	22.74	6.04 (3)	4.71 (3)	4.13 (2)	5.64 (1)		4.75 (1)
284	27.76	5.86 (3)	4.71 (3)	4.32 (1)			
291	Nov. 25.76	5.42 (3)	4.66 (3)				
2364	1913 Oct. 9.71	5.33 (3)	4.79 (2)	4.25 (1)		4.72 (½)	
2373	11.72	5.92 (3)	4.50 (2)				
2404	25.75	5.54 (3)	4.54 (2)	4.41 (1)			
2416	Nov. 1.71	6.07 (3)	4.71 (2)	4.14 (1)			
	Means,	5.76 (30)	4.74 (25)	4.38 (10)	5.64 (1)	5.48 (2½)	4.75 (1)

H. R. 1273. c 48 PERSEI

R. A. $4^h\ 1^m.4$; Decl. $+47°\ 27'$

Class, B3p. Magnitude, 4.03

PLATE NO.	GR. M. T.	WIDTHS OF EMISSION LINES Hβ	Hγ	Hδ
248	1911 Oct. 11.80	3.99 (2)	3.57 (1)	3.58 (½)
257	13.75	4.36 (2)	4.19 (1)	
285	27.79	4.05 (2)	3.76 (1½)	3.55 (½)
297	Nov. 29.83	4.32 (2)	3.51 (1½)	
298	29.85	4.27 (1)	3.75 (1½)	
304	Dec. 5.72		3.72 (1)	
305	5.73	3.79 (1)	3.68 (2)	
309	1912 Mar. 10.60	4.07 (1)	3.99 (½)	3.74 (½)
1230	Oct. 12.80	3.66 (2)	3.64 (2)	
1234	13.74	4.30 (1)	3.53 (1)	3.75 (½)
2366	1913 Oct. 9.77	3.84 (2)	3.35 (1)	3.13 (1)
3406	1915 Dec. 6.78	4.06 (2)	3.05 (1)	3.62 (1)
3410	9.76	4.68 (2)	3.74 (1)	3.38 (½)
3411	9.77	3.71 (1)	4.04 (1)	
	Means,	4.10 (21)	3.67 (17)	3.50 (4½)

H. R. 1622. 11 CAMELOPARDALIS

R. A. $4^h\ 57^m.4$; Decl. $+58°\ 50'$

Class, Bp. Magnitude, 5.31

PLATE NO.	GR. M. T.	WIDTHS OF EMISSION LINES Hβ	Hγ	Hδ	Hε	Hζ	Hη	Hθ	Hκ	Hν
3431	1916 Jan. 22.78		1.82 (2)	1.81 (3)	1.93 (2)	2.52 (2)	2.20 (2)		2.05 (½)	
3438	Feb. 29.68		1.62 (3)	2.60 (3)	1.89 (2)	2.08 (1)		2.12 (2)		
3439	29.76	1.78 (3)	1.72 (3)	1.84 (3)	2.55 (2)	2.14 (1)	2.24 (1)			
3442	Mar. 2.68			1.72 (3)		1.89 (2)	1.89 (2)	2.26 (1)	2.24 (1)	2.30 (1)
3455	16.70		1.82 (2)	1.60 (3)	1.93 (2)		2.24 (2)	2.18 (2)		2.02 (1)
3464	30.67	1.75 (2)	1.54 (3)	1.54 (3)						
3468	Apr. 3.68	1.72 (3)	1.62 (3)	1.67 (2)	2.08 (2)	2.28 (1)				
3472	6.68		1.72 (2)	1.64 (3)	1.79 (3)	2.08 (3)	2.36 (1)	2.26 (½)		
3495	17.66		1.58 (3)	2.00 (3)	2.01 (2)	1.80 (2)	2.05 (1)	2.23 (1)		
	Means,	1.75 (8)	1.66 (21)	1.72 (26)	2.01 (15)	2.10 (12)	2.15 (9)	2.19 (6½)	2.18 (1½)	2.16 (2)

H. R. 2357. β 11 MONOCEROTIS, (Brightest Component)

R.A. $6^h\ 24^m.0$; Decl. $+6°\ 58'$

Class, B3p. Magnitude, 4.73

PLATE NO.	GR. M. T.	WIDTHS OF EMISSION LINES						
		Hβ	Hγ	Hδ	λ4630	λ4584	λ4352	λ4233
2411	1913 Oct. 31.79	6.13 (2)	4.81 (1)	3.92 (1)		5.50 (1)		
2441	Nov. 16.77	6.28 (2)	4.04 (2)	4.20 (1)	4.85 (½)			
2501	Dec. 14.78	5.77 (3)	5.17 (3)			5.07 (1)	3.84 (½)	
2556	1914 Feb. 1.68	6.33 (3)	5.05 (3)	3.89 (1)	5.81 (1)	6.18 (½)		4.92 (1)
2652	Mar. 19.56	6.66 (3)	4.54 (3)	5.04 (1)	5.12 (½)	6.51 (½)		
3043	Oct. 30.92	7.21 (2)	5.19 (3)	4.90 (1)	5.85 (1)	6.05 (1)		4.92 (1)
3045	Nov. 1.80	6.21 (3)	4.73 (2)	4.30 (1)				
3046	1.86	6.55 (3)	5.09 (2)	4.80 (2)				
3061	22.80	6.61 (3)	5.03 (3)	4.24 (1)	5.07 (1)		5.14 (1)	
3062	22.85	6.46 (3)	4.65 (3)	3.71 (1)		5.40 (1)		
3071	27.76	5.83 (3)	5.13 (3)	4.22 (1)			4.90 (1)	
	Means,	6.35 (30)	4.95 (28)	4.36 (11)	5.43 (4)	5.67 (5)	4.78 (2½)	4.92 (1)

Plate 3045 also gave Hζ 3.86 (1).

H. R. 7708. b^2 28 CYGNI

R. A. $20^h\ 5^m.7$; Decl. $+36°\ 33'$

Class, B2p. Magnitude, 4.82

PLATE NO.	GR. M. T.	WIDTHS OF EMISSION LINES		
		Hβ	Hγ	Hδ
73	1911 July 1.73	5.02 (2)	4.45 (1)	4.02 (1)
113	11.80	6.63 (1)	5.17 (½)	
155	27.79	6.30 (2)	5.24 (1)	4.22 (1)
166	31.74	6.45 (2)		
234	Oct. 2.70	6.33 (2)	5.07 (½)	4.86 (½)
243	11.58	5.86 (1)	4.83 (1)	4.05 (½)
1301	1912 Oct. 19.64	6.45 (1)		4.44 (1)
3489	1916 Apr. 9.90	6.65 (1)	5.19 (1)	4.48 (½)
3507	June 4.82	6.08 (1)	5.31 (½)	4.32 (½)
3535	July 6.44	6.24 (2)	5.31 (1)	4.43 (1)
	Means,	6.31 (16)	5.04 (6½)	4.37 (6½)

H. R. 8047. f^1 CYGNI

R.A. $20^h\ 56^m.4$; Decl. $+47°\ 8'$

Class, Bp. Magnitude, 4.86

PLATE NO.	GR. M. T.	WIDTHS OF EMISSION LINES	
		Hβ	Hγ
66	1911 June 30.81	10.98 (½)	7.96 (½)
87	July 5.80	9.89 (½)	
114	11.87	10.42 (½)	8.26 (½)
150	26.77	11.54 (½)	8.45 (½)
162	30.77	9.89 (1)	
227	Sept. 27.69	10.98 (1)	8.30 (½)
	Second measure	10.15 (1)	8.30 (½)
1197	1912 Oct. 6.67	10.89 (½)	
	Means,	10.51 (4½)	8.24 (2)

H. R. 8539. π AQUARII

R.A. $22^h\ 20^m.2$; Decl. $+0°\ 52'$

Class, B1p. Magnitude, 4.64

PLATE NO.	GR. M. T.	WIDTHS OF EMISSION LINES		
		Hβ	Hγ	Hδ
209	1911 Sept. 19.75	7.81 (2)	6.69 (½)	
219	23.73	7.70 (2)	6.00 (1)	
228	27.75	7.93 (2)	6.65 (1)	
244	Oct. 11.58	7.46 (2)	5.55 (½)	
249	12.70	7.10 (2)	5.68 (1)	5.19 (1)
262	18.67	7.07 (2)	5.87 (1)	
288	Nov. 22.58	6.87 (2)	5.93 (2)	
1302	1912 Oct. 19.68	7.43 (2)	5.40 (2)	5.01 (1)
	Means,	7.42 (16)	5.89 (9)	5.10 (2)

H. R. 8773. β 4 PISCIUM

R. A. $22^h\ 58^m.8$; Decl. $+3°\ 17'$

Class, B5p. Magnitude, 4.58

PLATE NO.	GR. M. T.	WIDTHS OF EMISSION LINES			
		Hβ	Hγ	Hδ	Hε
205	1911 Sept. 13.75	2.51 (2)	2.61 (2)	2.84 (1)	2.87 (1)
220	23.77	2.66 (2)	2.47 (2)	2.76 (1)	
225	26.77	2.51 (2)	2.66 (2)	2.57 (½)	2.48 (½)
245	Oct. 11.71	2.37 (2)	2.47 (2)	2.61 (2)	
263	18.71	2.66 (2)	2.47 (2)		2.58 (½)
281	27.67	2.51 (2)	2.47 (2)	2.84 (1)	2.84 (½)
289	Nov. 22.62	2.66 (2)	2.47 (1)		
299	Dec. 5.60	3.08 (2)	2.47 (1)	2.39 (1)	
1115	1912 Sept. 28.75	2.51 (2)	2.66 (2)	2.87 (1)	
1191	Oct. 5.72	2.72 (2)	2.38 (2)	2.69 (1)	
	Means,	2.62 (20)	2.52 (18)	2.69 (8½)	2.73 (2½)

The mean results for each hydrogen line are collected with corresponding weights in Table 2 for each of the twelve stars.

DISCUSSION OF DATA

The data of Table 2 are plotted in Fig. 1 for each star. In this plate the abscissæ are wave-lengths in angstroms and the ordinates line-widths in the same unit. The plotted points in Fig. 1, when three or more are determined, indicate strongly a linear relation between line width in angstroms and wave-length for the hydrogen emission lines of each star. Drawing these lines for each case, including f^1 Cygni and κ Draconis for which only two lines were measurable, it is quite evident that their slope from star to star varies, increasing positively with the width of the Hβ line. For an Hβ line width of approximately 2.61 A the line widths do not change with wave-length but for narrower Hβ they decrease with increasing wave-length and for an Hβ wider than 2.61 A they increase with in-

TABLE 2

MEAN WIDTH OF HYDROGEN EMISSION LINES IN CLASS B SPECTRA

STARS	WIDTHS OF EMISSION LINES				
	Hβ	Hγ	Hδ	Hε	Hζ
f^1 Cygni	10.51 (4½)	8.24 (2)			
π Aquarii	7.42 (16)	5.89 (9)	5.10 (2)		
φ Persei	6.98 (30)	5.61 (24)	5.13 (13)		
H. R. 985	6.65 (16)	5.30 (6)	4.73 (2)		
β Monocerotis*	6.35 (30)	4.95 (28)	4.36 (11)		3.86 (1)
b^2 Cygni	6.31 (16)	5.04 (6½)	4.37 (6)		
ψ Persei	5.76 (30)	4.74 (25)	4.38 (10)		
κ Draconis	5.16 (48)	4.26 (23)			
γ Cassiopeiæ	5.06 (70)	4.38 (64)	3.94 (32)		3.79 (2)
ε Persei	4.10 (21)	3.67 (17)	3.50 (4½)		
β Piscium	2.62 (20)	2.52 (18)	2.69 (8½)	2.73 (2½)	
11 Camelopardalis		1.66 (21)	1.72 (26)	2.01 (15)	2.10 (12)

Additional measures: 11 Camelopardalis, Hη, 2.15 (9); Hθ, 2.19 (6½); Hκ, 2.18 (1½) Hν, 2.16 (2).

*Brightest component.

creasing wave-length. Furthermore all these lines converge roughly at λ 3270, suggesting that if a line were present in this region it would have the same width in all of these stars.

Expressing these deductions quantitatively, equations for the dotted straight lines for each star in Fig. I are given in Table 3. The quantity, a, in this table is discussed below.

TABLE 3

f^1 Cygni	$\Delta\lambda = +0.00437\lambda - 10.75,$	$a = +0.00507$
π Aquarii	$\Delta\lambda = +0.00296\lambda \quad 6.99,$	$a = +0.00302$
φ Persei	$\Delta\lambda = +0.00260\lambda \quad 5.62,$	$a = +0.00287$
H. R. 985	$\Delta\lambda = +0.00257\lambda \quad 5.84,$	$a = +0.00252$
β Monocerotis*	$\Delta\lambda = +0.00262\lambda \quad 6.39,$	$a = +0.00225$
b^2 Cygni	$\Delta\lambda = +0.00247\lambda \quad 5.70,$	$a = +0.00225$
ψ Persei	$\Delta\lambda = +0.00192\lambda \quad 3.55,$	$a = +0.00203$
γ Cassiopeiæ	$\Delta\lambda = +0.00137\lambda - 1.59,$	$a = +0.00160$
ε Persei	$\Delta\lambda = +0.00081\lambda + 0.17,$	$a = +0.00099$
β Piscium	$\Delta\lambda = -0.00005\lambda \quad 2.50,$	$a = +0.00001$
11 Camelopardalis	$\Delta\lambda = -0.00108\lambda + 6.25,$	

*Brightest component.

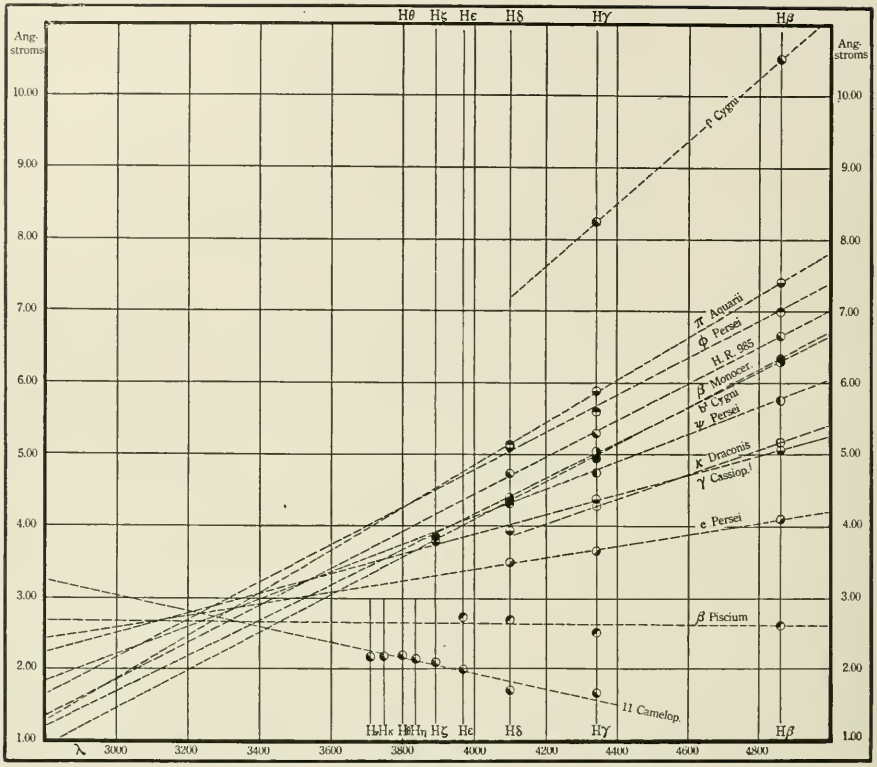


FIG. I. CLASS Bp STELLAR SPECTRA. EMISSION LINE WIDTHS PLOTTED AGAINST WAVE LENGTHS

Solving by least squares for the intersection of these lines (excluding f^1 Cygni and κ Draconis, because of limited data, and 11 Camelopardalis, because in this case the narrow lines may be affected by slit width) we obtain the values: $\Delta\lambda = 2.61$ A, $\lambda = 3270$ A. It is notable that a circle about this point with a radius of 0.5 A would be intersected by all the lines drawn. If now we assume that all the lines of the figure pass through this point, we may derive for each star an equation of the form,

$$\Delta\lambda = (\lambda - 3270)\, a + 2.61.$$

Values of a on this basis are given in the last column of Table 3. Again, if the width of the $H\beta$ line in any star be designated by W, the inclination of the line representing the relation between line width and wave-length for that star will be represented by the equation:

$$a = \frac{W - 2.61}{4862 - 3270}$$

Combining the last two equations for any star we may write the general equation for the width of any hydrogen emission line of this class,

$$\Delta\lambda = 6.28 \times 10^{-4} (\lambda - 3270)(W - 2.61) + 2.61.$$

Using the measured values of the width of $H\beta$ *in Table 2, we can compute by this formula the width*

of any emission line in the table for the second to tenth stars within 0.30 A *and usually much less.* For f[1] Cygni the results were perforce of inferior quality but even these are represented within 0.40 A. If we draw through the intersection point (λ, 3270; Δλ, 2.61) straight lines satisfying best the observations of each star, the greatest residual for any well determined line is about 0.15 A and for the poorest line, 0.20 A. In brief, all the line widths in angstroms of hydrogen emission lines in these stars, when plotted against wave-lengths, are represented well by a pencil of straight lines passing through the point, λ = 3270A, Δλ = 2.61A. *More generally when we know the width of the Hβ emission line in any one of these stars, we can derive a good value of the width of any other emission line in the region of the spectrum studied here.*

THE METALLIC LINES

The means of the results for the metallic emission line widths are collected in Table 4. For each line the width in angstroms, the weight, and the residual in angstroms from the dotted line of Fig. 1, is given for each star where measures could be made. It is a notable fact that these line widths do not deviate far from the values interpolated from the hydrogen lines in the same star. Such deviation on the average is 0.3 A. In Phi Persei they fall consistently below the hydrogen lines by about 0.25 A or roughly 5 per cent. In Psi Persei they are about the same amount wider than would be expected from the hydrogen lines. But considering the difficulties of measurement it is hardly safe to say that the metallic line widths differ from those of hydrogen. On the other hand we can say, taking into account the difficulties of measurement, that the widths of the metallic emission lines agree well with the results for hydrogen. Their widths are certainly of the same order as those of hydrogen in the same region and vary in the same way with wave-length.

RELATED STUDIES

A quantity closely related to the width of emission lines in Class B spectra has been measured for several stars by Doctor P. W. Merrill. It is the distance in angstroms between the centers of the two parts of the emission components of any doubly reversed line. These studies, so far as they go, accord well with the results for line widths described above.

DEDUCTIONS

The well known structure and intensity relations of the distinctive Class Bp lines point to certain fairly definite conclusions with reference to the atmospheric structure of the stars in this group. An absorbing layer about the star's "nucleus" produces wide absorption lines. An extensive layer of hydrogen often accompanied by iron vapor and probably other constituents overlies the absorbing layer and emits bright line radiation in the Balmer series of hydrogen in many cases weaker than the neighboring continuous spectrum, but strong enough in one or more of the hydrogen lines of greater wave-length to be recognized within the absorption lines on which they are superposed. A more rare and less emissive layer containing

TABLE 4
WIDTHS OF METALLIC EMISSION LINES IN ANGSTROMS

STARS	λ4630			λ4584			λ4385			λ4352			λ4233		
	Width	p	Resid.	Width	p	Resid.	Width	p	Resid.	Width	p	Resid.	Width	p	Resid.
φ Persei	6.19	8	−0.25	6.00	4	−0.32				5.30	3	−0.27	5.18	2	−0.22
β Monocerotis	5.43	4	−0.32	5.67	5	+0.05				4.78	2½	−0.24	4.92	1	+0 22
ψ Persei	5.64	1	+0.30	5.48	2½	+0.23							4.75	1	+0.18
γ Cassiopeiæ				5.28	15	+0.60	4.43	3	+0.03				4.03	5	−0.17

hydrogen surrounds the whole and produces a second reversal which is often strong enough to be seen in these lines.

It is not to be assumed that the emission component in each of the hydrogen lines in a given star comes from the same atmospheric layer nor from mutually exclusive atmospheric shells. We can consider the region of the atmosphere from which the radiation in any emission line does come to be a spherical shell, different in any star for the several lines though overlapping more or less. There is reason to think that the mean altitude of the layer which yields predominatingly the radiation in any given emission line increases in general with the wave-length of the line. We find a counterpart to this of limited scope in the atmosphere of the sun and account for it on the theory that the higher layers of the stellar atmospheres are cooler or otherwise physically different in such a manner that they radiate light in which the greater wave-lengths predominate. In the Class Bp spectra the intensity of the emission lines of hydrogen increases with increasing wave-length probably for two reasons — both because the entire phenomenon is a "low temperature" one and because the extent of atmosphere producing the radiation in these spectral lines decreases effectively with decreasing wave-length, the outer, "cooler" layers making more important contributions to the emission lines of greater wave-length; the progressively less extensive, "hotter" layers to lines of progressively smaller wave-length.

If we account for the peculiar lines of Class Bp spectra in accordance with the suggestions of the last two paragraphs, we can find explanation for variations of different types with wave-length in the widths of the emission lines of different stars.

There are at least three widening agencies which may be active in the sources from which comes the emission line radiation of these stars: vapor density or pressure, radial motion due to rotation, and radial motion due to convection currents. Certainly in stars whose spectra contain broad emission lines, vapor density or pressure may be considered a predominating influence in line widening, though such pressure may be a local effect, accompanying electrical discharge for example, if such discharge is the source of this radiation.

Doppler displacements due to rotational velocities may contribute something to the widening of these emission lines. However the sharp, dark, second reversals in many of these hydrogen lines indicate that the outer layers of the atmosphere are not in rapid motion due to rotation. If then the inner atmosphere is rotating rapidly enough to contribute in an important degree to the widening of the broad absorption and emission lines in any of these spectra it follows that the outer layers do not share the rotation of the region below. In this connection it is interesting to note that in this case frictional disturbances would be present in these atmospheres which through heat and electrical phenomena would contribute to the emission observed. However, admitting this possibility, it seems probable that rotation is not as a rule an important factor in line widening in the stars considered. But in narrow lines, for which the vapor density effect is certainly small, widening due to rotation may be relatively prominent. And line widening resulting from Doppler displacements due to convection currents may be of some importance in this connection.

Line widening due to vapor density or pressure increases with pressure and with wave-length. Hence if the atmospheric shells which predominate in the production of the various hydrogen lines are essentially identical in any star we should expect the line widths to increase with increasing wave-length. If on the other hand the effective altitudes of the various atmospheric shells which contribute to the radiation in the several emission lines of any star increase with increasing wave-length we can postulate a corresponding decrease in pressure or vapor density, in which case a factor would be introduced tending to produce a decrease in line-widths with increasing wave-length. We thus have two opposing factors entering with different relative effectiveness in different stars.

In stars having the broader hydrogen emission lines of greater wave-length with sharp narrow reversals, we undoubtedly have a wide range of pressure represented in any one emission line. Probably, therefore, the atmospheric layer emitting such a bright line is a thick one,

the narrower layer under highest effective pressure emitting the radiation which determines the total width of this bright line is effectively far down in the star's atmosphere, and very nearly the same (or a slightly inferior) layer is the effective source of the hydrogen emission lines of smaller wave-length. In this case then we should expect the line widths to increase with increasing wave-length, in accordance with the determinations described above. But in stars having the narrower hydrogen emission lines of greater wave-length the pressure or vapor density range in the atmospheric shell emitting such lines is relatively small. This may indicate that the mass and surface gravity of such a star is relatively small or that the atmospheric shells are relatively thin. For stars in which these atmospheric shells are relatively thin it seems reasonable that the shells emitting the bright lines of different wave-length should vary in diameter, and, more particularly, that the radiation of atmospheric shells of decreasing diameter, averaging "hotter", should predominate increasingly in the lines of shorter wave-length. And since such emission lines of shorter wave-length are relatively faint, the contribution of such hot lower layers to the emission lines of greater wave-length can be considered relatively small. But if the mean diameters of the atmospheric shells which predominate in the emission determining the total widths of the lines decrease with shorter wave-length, then the increased pressure and vapor density in these shells of smaller diameter would increase progressively the width of these lines of shorter wave-length, opposing, and in some cases perhaps, overcoming the reverse effect of increased widening with increasing wave-length known to characterize pressure widening in a given layer. Apparently we may thus account for the varied relations between line widths and wave-lengths found above for emission lines in Class Bp spectra.

In narrow lines where pressure or vapor density effects are small, widening due to rotation may be relatively important. Such widening would increase with wave-length for any layer but would decrease with wave-length for layers of decreasing altitude if the atmosphere had the same angular rotational velocity throughout or more so if the lower layer rotated progressively more slowly. On the other hand, if the upper layers rotated progressively more slowly with increasing altitude the reverse might be the case. Thus the relations between line widths and wave-lengths so far as this factor is concerned might vary from star to star in a manner similar to but less pronounced than that discussed above for vapor density or pressure.

Line widening due to convection currents would increase almost directly with the wave-length, for the limited region of the spectrum considered, in the integrated light from any one layer, unless perhaps the more rapid convection currents in such a layer are effectively hotter and predominate in the lines of shorter wave-length. In any star the current velocities would vary in different layers, being perhaps greater in the lower "hotter" layers which probably participate more effectively in the radiation of smaller wave-length. If so this condition would tend to produce increase of line width with decreasing wave-length. If again we assume as above that the mean diameter of the atmospheric shells contributing emission determining the width of spectral lines in any spectrum of this class decreases more effectively with wave-length if the lines of greater wave-length are narrow, we can account for the observed variations of emission line widths with wave-lengths in different spectra on the basis of convection current velocities, as worked out on the basis of vapor density or pressure above.

The explanations offered here are intended chiefly to account for the observed changes in width of emission lines in Class Bp stars with wave-length whether that change represents an increase or a decrease or the special case of approximate constancy. So far as known the explanations proposed would not presuppose a strictly linear relation between line width and wave-length in any star — certainly not in every case. Nor are the straight lines drawn in the figure and expressed by equations in Table 3 considered as any better than approximations to the actual curves which would depict the relations between these quantities for the twelve stars studied over a great extent of their spectrum. Such straight lines do express these relations closely for the range of wave-lengths studied, and so far as they can not be

accounted for on the basis of laboratory results, they throw light on the nature of the variation of line width with wave-length, especially in stellar atmospheres.

The convergence of the lines in the figure at about λ 3270 undoubtedly has some physical meaning. On the basis of the suggestions made above this convergence would indicate that radiations of this wave-length, if they existed, would be emitted in all of these stars only under a similar totality of conditions of pressure, and perhaps of atmospheric circulation, in each case. On the other hand other radiation, such as that of Hβ, in emission lines in these spectra, is emitted under widely differing conditions of the source in different stars and perhaps in the same star.

SUMMARY

The present paper describes a quantitative investigation of the line widths of the emission components of hydrogen and metallic lines in eleven Class Bp stellar spectra, as measured in the photographic region on 182 spectrograms made at the Detroit Observatory with the single prism spectrograph. Similar data for a twelfth star from measures made at this Observatory by Professor R. H. Baker are also discussed.

The width of an emission line was taken as the difference in wave-length between the centers of the density gradients which stand out sharply at the edges of such a line under exposure timed to bring out clearly the features involved. Thus the factors tending to modify the measured line widths were in a great measure controlled.

The results are shown in Fig. 1. By the measures on the hydrogen lines, when three or more lines are available, a linear relation between line width in angstroms and wave-length in the same unit is well brought out for the region considered. The slope of these lines expressing the variation of line width with wave-length varies from star to star, increasing positively with, and remaining a simple function of, the width of the Hβ emission line. For an Hβ line width of approximately 2.61 A, all the emission lines are of the same width, but for narrower Hβ they decrease in width with increasing wave-length, and in spectra where the Hβ emission is wider than 2.61 A they increase with increasing wave-length. Furthermore, the lines expressing the variation of spectral line width with wave-length converge roughly at λ 3270, suggesting that if a line were present in this region it would have about the same width in all of these stars.

All of the line widths in angstroms of hydrogen emission lines in the eleven stars studied, when plotted against wave-lengths, are represented well by a pencil of straight lines passing through the point, λ = 3270 A, Δλ = 2.61 A.

Thus, when we know the width of the Hβ emission line in the spectrum of any one of the stars we can determine from it a good value of the width of any other hydrogen emission line in that spectrum. A general formula for the computation of the width (Δλ) of any hydrogen emission line of mean wave-length, λ, if W is the width of the Hβ line is, in angstroms,

$$\Delta\lambda = 6.28 \times 10^{-4} (\lambda - 3270) (W - 2.61) + 2.61.$$

The metallic emission line widths are of the same order as those of hydrogen in the same region and vary in the same way with wave-length.

In explanation of the observed results described above it is first assumed in accordance with the well known structure and intensity relations of the distinctive Class Bp lines, that an extensive layer of hydrogen, perhaps always mixed with iron and other metals, emits radiation in the Balmer series of hydrogen strong enough in one or more of the hydrogen lines of greater wave-length to be recognized against the absorption background on which such radiation is superposed.

Assuming an extensive layer of hydrogen the widening of the emission lines due to this layer is attributed to pressure or vapor density, possibly accompanying electrical discharge, and in some measure also to Doppler effects associated with convection currents or rotation. One or all of these widening agencies may be active in any star and if the source of the radiation in the emission components of all the hydrogen lines in any spectrum is effectively the same (*i.e.* if such radiation comes in the same relative intensity from all parts of the same layer) we expect the width of such emission components to increase with wave-length. If, however, in any star the

radiation determining the width of the hydrogen emission lines comes from layers of the atmosphere effectively lower and hotter the shorter the wave-length, the higher density and more rapid convection currents in such lower layers would lead to an increase of line width with decreasing wave-length. Variation of line width with wave-length in any star would result from a combination of these factors at least.

If the Hβ line is narrow the emission comes from a layer under pressure or with density, both of narrow range. This layer is probably a thin atmospheric shell and the layers yielding the lines of shorter wave-length are effectively lower and under higher pressure. In this case the factor increasing the line width with decreasing wave-length may predominate. For a wide Hβ line the emission comes from a layer under pressures of wide range, probably a thick atmospheric shell, and the layers yielding the lines of shorter wave-length are effectively the same. In this case the factor tending to increase line width with increasing wave-length prevails. Between the two extremes innumerable intermediate types may occur. And we may reason similarly for widening effects due to convection and possibly to rotation.

The passage through the point, $\lambda = 3270$ A, $\Delta\lambda = 2.61$ A, of the pencil of straight lines representing well the relation between line width and wave-length, suggests that in all stars of the group studied the width of a hypothetical emission line at λ3270 would be not far from the value, 2.61 A. But with increasing wave-length the widths of any line in different stars of the group may differ increasingly. This is construed to mean that the hypothetical emission line at λ3270 would be produced always under a similar totality of conditions of pressure or other widening agencies but that with increasing wave-length the radiation in any line is emitted under very different conditions in different stars.

The twelve stars considered in this paper are probably not unique in respect to the characteristics brought out, among objects having spectra in Class Bp. It would be of interest to know whether the spectra of all stars of this bright line group exhibit relations between line width and wave-length in conformity with those brought out in the present investigation. These studies will be extended to other stars of this kind when suitable emission lines are found in their spectra.

Ann Arbor, Michigan, 1920.

STUDIES OF CLASS B STELLAR SPECTRA CONTAINING EMISSION LINES

SIXTH PAPER

By RALPH H. CURTISS

The stars whose spectra are classified under the designation B or A, with the peculiarity that hydrogen lines in the Huggins series, and sometimes other lines, have emission components strong enough to be observed, form one of the few stellar groups concerning the place of which in the evolutionary sequence or sequences there is still some doubt. Several possibilities suggest themselves from which it is hoped that a choice can be made.

It is the purpose of this paper to collect and discuss some data which have come to light recently bearing upon the nature of these stars and upon their relation to some stellar evolutionary plan.

NUMBER

A better idea of the number of these stars has resulted from the extensive surveys of spectra for the *Henry Draper Catalogue*, of stars to magnitude 8.5 when photographed at Cambridge and to 9.0 at Arequipa. In other lists, 110 stars were found. The number of additional stars with visible hydrogen emission in the photographic region found among the 241,000 spectra (222,000 stars) of the *Henry Draper Catalogue*, was announced as twenty by Miss Cannon in 1916. Thus a total of about 130 of these stars had been listed at Harvard in the entire sky. Within the region from 0 to 11 hours inclusive in right ascension, covered by the first four volumes of the *Henry Draper Catalogue*, now issued, sixty of these objects had been announced. In the new catalogue, nine are eliminated, four by changed classification, four faint objects by assignment to the doubtful list, and one faint star through omission. Only fourteen new objects are added, making a net gain of five stars in twelve hours of right ascension. However, a number of Class B spectra with suspected bright $H\beta$ or with faint dark $H\beta$ probably have bright $H\alpha$ and will be included in this class. Further additions may increase the total in this group to more than two hundred members brighter than magnitudes 8.5 and 9.0. In November, 1920, the writer's list included 123 stars known to have spectra in Class B with hydrogen emission visible now or in the past. Subsequently twenty more stars have been added to the group through discoveries by Merrill and Humason, and two more by Miss Cannon.

SPECTRAL AFFILIATIONS

Of particular significance, in connection with the spectral affiliations of these stars, is the strong tendency, in reclassifications, to move those which have been classed lower than B8 toward B0 in the scale. Two faint stars with spectra classified as F0 and one each as A2 and A5 in the former lists influenced generalizations relative to the group and were quite misleading. Three of these are now assigned to the earlier divisions of Class B in the *Henry Draper Catalogue* and the fourth is eliminated entirely from the list. All the stars in this group are now classed from B0 to A0 inclusive, so far as published data go, and many of those originally assigned to Class A0 have been placed in some division of Class B. The two bright stars with spectra classed as Ap are 25 Vulpeculæ and α Aræ. Detroit Observatory spectrograms of the former show a spectrum of B8 or above. The latter cannot be reached from this latitude, but Miss Cannon classified it as B3 in Volume 28 of the *Harvard Annals*. Only five bright line spectra are left in Class Ap and

only one of these belongs to a star brighter than seventh magnitude.

On the other hand it should not be overlooked that studies in the Hα region may add more than a few stars with spectra in Class A to this group. The case of α Cygni, which has not been included in the group, as discussed in this paper, may be cited in this connection. The spectrum of this star is classed as A2p and contains Hα emission accompanied by displaced absorption. But in this spectrum helium is represented raising the question as to the finality of the above assigned class.

The effect of revision on the old classification of the stars of this group is brought out strongly in the first twelve hours of the *Henry Draper Catalogue*. Of the sixty stars in the old lists, seventeen were classed as Ap, one as A5p, and two as Fop. Of the latter three, one is changed to Go in the *Henry Draper Catalogue* and the other two to Bop. Of the seventeen Class Ap spectra, four are placed in the revision in early divisions of Class Bp, another in Class B, five are of P Cygni type, three are planetary nebulæ, three are "Pec.", and one is omitted in the new catalogue. *No object remains outside of the limits,* Bo *to* B8, *and only two outside of the limits* Bo *to* B5. And there is reason to think that the extension of this revision to the rest of the sky has led to similar results, for the seven hydrogen emission stars of Class A of which reclassifications have not been published are, with the two exceptions noted above, faint objects with spectra the more difficult to classify because the dark lines, excepting the hydrogen double reversals, are usually very diffuse.

There is another consideration tending to support the conclusion that the hydrogen emission stars of Classes Bo to Ao belong in greater proportion to the earlier divisions of Class B than former catalogues have indicated. Probably there exist undetected in this group binaries like Beta Lyræ, having a bright line component in the upper divisions of Class B associated with a dark line star of Class B8 or A. Not in all cases could the composite character be recognized without quantitative measures. Some of the hydrogen spectra that may remain in Classes B8 and Ao after the Harvard revision is complete may be accounted for in this way.

RELATIVE BRIGHTNESS

In former lists of these stars the erroneous assignment of many fainter stars to Class Ap tended to increase artificially the average catalogue brightness of those remaining in Class Bp, especially as compared with those in Class Ap. This greater brightness of the Class Bp stars as compared with those of Class Ap in former lists has been brought out by the writer.

The reclassification of these stars is making it possible to determine whether the Class B stars having bright hydrogen lines are really more numerous proportionally among the brighter members of this spectral class. In the *Henry Draper Catalogue* data for this purpose are available over twelve hours of right ascension. A count, given in the accompanying table, reveals the fact for the stars of Classes Bo to B5, that one in six is known to have bright lines for magnitudes brighter than 4.0, one in fifteen between magnitudes 4.0 and 6.9 inclusive, one in sixty-five between magnitudes 7.0 and 9.9 inclusive. Or if we include twenty-nine other stars of this class range having suspected bright Hβ, these ratios become one to five for the stars brighter than 4.0, one to thirteen between magnitudes 4.0 and 6.9, and one to twenty-eight between magnitudes 7.0 and 9.9. The actual numbers are given in the accompanying tables.

In the region considered, the stars of Class B having bright hydrogen lines are much more numerous relatively among the brighter stars of this class than among the fainter stars. If this remarkable condition were a peculiarity of the region considered it would be still more extraordinary; but such is undoubtedly not the case. Unless an important discovery factor dependent on brightness is present here the stars of Class Bp are much more numerous relatively among the brighter stars of this class, where found, over the whole sky. In other words these emission line stars are bright on the average in their class. And since there is no reason to consider them closer to us than the normal of their class, the conclusion is that they are larger or effectively brighter superficially

than the average Class Bo to B5 star. Probably an extensive atmosphere would not be conducive to greater surface brightness. Nor is there any indication of greater surface brightness for these stars due to preponderance of spectra in the first two or three subdivisions of Class B. Probably they are larger. If larger, they are more massive or less dense (not including the hydrogen envelope) than the average of their class, perhaps both. Both of these characteristics of great mass and low density could be favorable to or associated with the existence of an extensive luminescent or luminous hydrogen envelope.

COUNTS OF STARS BY MAGNITUDES IN THE HENRY DRAPER CATALOGUE IN CLASSES Bo TO B5 AND Bop TO B5p, BETWEEN 0^h AND 12^h OF RIGHT ASCENSION

MAGNITUDES	CLASSES OF STARS	
	Bo to B5	Bop to B5p
0.0 to 1.9	7	0
2.0 to 2.9	12	3
3.0 to 3.9	26	5
4.0 to 4.9	111	16
5.0 to 5.9	196	12
6.0 to 6.9	277	11
7.0 to 7.9	389	7
8.0 to 8.9	514	6
9.0 to 9.9	199	4

PHOTOGRAPHIC MAGNITUDE	CLASSES OF STARS			PROPORTION WITH EMISSION	PROPORTION WITH EMISSION, INCLUDING SUSPECTED CASES
	Bo to B5	Bop to B5p	SUSPECTED Bop to B5p		
0.0 to 3.9	45	8	1	1 to 5.6	1 to 5.0
4.0 to 6.9	584	39	5	1 to 15.0	1 to 13.3
7.0 to 9.9	1102	17	23	1 to 64.8	1 to 27.5

Stars classified simply as B are included in the counts.

MOTIONS

For the stars with spectra in Class Bp the average residual radial velocity and the average component of proper motion at right angles to the direction toward the solar apex are not known to differ from the same quantities for other stars of the same spectral classification without visible bright lines. Actual numerical values in this connection are of interest. Twenty-one stars with bright line spectra in Class B are found in Campbell's list of 225 Class B stars from which he has derived the average residual velocity for the class. Assuming for the solar apex the elements: right ascension, 270°; declination, +30°; velocity, 20.2 kilometers per second, the average residual radial velocity for the 225 stars is 6.5 kilometers per second. For the twenty-one stars with Class Bp spectra having bright lines the average residual radial velocity is 6.7 kilometers per second. The average component of proper motion at right angles to the direction toward the solar apex for the 225 stars with Class B spectra is 0.″0099; for the twenty-one with bright lines in their spectra, 0.″0082. This agreement, in a measure perhaps accidental, indicates that stars with bright line spectra in Class B do not stand apart from other stars of the class in respect to residual motions.

PROGRESSIVE VARIATIONS

Variations of a remarkable character in the emission lines of a number of spectra of Classes Bop to Aop have been observed in connection

with studies of the stars of this group. Investigation of such variations will undoubtedly throw light upon the nature of these stars. Of most striking significance are secular variations involving the total or partial fading out of strong emission lines and their replacement by absorption. As studies of these stars multiply and the time factor increases, cases of secular changes of marked character are coming to light. Three important examples of secular or at least long period change involving the disappearance of emission lines as such will be reviewed here in detail with the addition of evidence secured at this Observatory when available.

Pleione furnishes the first well established case of complete disappearance of emission lines. On December 28, 1888, bright Hβ was well shown on an objective prism spectrogram made at Harvard College Observatory. In 1889, Keeler found Hα and Hβ bright, and Miss Maury recorded Hβ and Hγ bright on broad absorption (*i. e.* these were broad absorption lines reversed). About 1891, several spectrograms made at Potsdam showed the emission lines of hydrogen plainly. In 1895, Campbell found Hα bright. Twenty-two plates taken at Harvard on thirteen nights in the autumn of 1896 gave no certain evidence of changes in bright Hβ. On December 31, 1896, bright Hβ was still well shown. In 1905, November and December, and 1906, January and February, Frost noted the faintness or absence of the hydrogen emission lines (probably Hβ and Hγ) in the region covered by his plates. This was confirmed immediately at Harvard. In 1910, December 2, and 1911, January 2, Wright found Hα and Hβ dark. In 1912, July 28, Merrill found Hβ, and on September 9, both Hα and Hβ to be strong, clear absorption lines. At the Detroit Observatory on the following dates the presence of strong broad hydrogen absorption lines without reversal in the photographic region of Pleione's spectrum is established: 1912, December 14; 1913, December 14 and 21; 1915, November 9 and 17 and December 3; 1920, November 3 and 27, and December 20; 1921, September 30. And strong dark Hα was photographed here in 1913, December 21, and 1915, December 3.

From single-prism spectrograms in the photographic region of Pleione's spectrum made at Potsdam by Hartmann during the critical period of disappearance of the hydrogen reversals, Doctor Jung has given us an account of this change which helps to complete the story. [The Radial Velocity of Eleven Pleiades Stars. Johannes H. W. Jung, Göttingen, 1914. pp. 32–35.] In 1903, on January 17, 18, and February 2, double reversals of the hydrogen lines were clearly shown. In 1906, on November 20, the reversal was hardly noticeable. On December 22 of the same year the hydrogen lines were broad and diffuse with no reversals recognizable as such. A month later the hydrogen lines though well shown were not reversed. Finally in 1908, on January 2, a beautiful broad spectrum showed no trace of reversal in the absorption lines. Apparently the hydrogen reversals in the photographic region of Pleione's spectrum disappeared late in 1906 and were difficult objects for some months before that.

The hydrogen absorption lines now present in this spectrum are very wide, such as those found reversed in many Class Bp spectra. Probably their width changed little if any when the reversal disappeared. And in the same connection it seems improbable that there was any important change in the extent or density of the star's atmosphere. It seems probable then that the factors exciting luminosity in the atmosphere have been altered. Apparently an extensive atmosphere may be a necessary condition for the existence of visible hydrogen emission in Class B spectra but it is not a sufficient one.

The case of f^1 Cygni appears to be no less remarkable than that of Pleione. On the basis of four objective-prism spectrograms covering a short period beginning November 15, 1904, Miss Cannon describes the hydrogen lines from Hβ to Hζ as bright and superposed on wide, hazy, dark bands. Indeed these emission lines in the spectrum of f^1 Cygni were stronger than the corresponding lines in any one of sixteen of this group included in a table in *Harvard Annals*, Volume 56, page 112. And this table contained such strong emission line stars as 11 Camelopardalis, Chi Ophiuchi, and Beta Piscium. A two-prism spectrogram of August

27, 1909, kindly loaned by Professor E. B. Frost, shows a fairly sharp Hβ dark line but no certain hydrogen emission. Apparently the absorption borders that mark off the emission at Hβ in 1911 were not brought out. In 1911, May 29, Merrill found Hβ possibly and Hγ probably bright on absorption but the limitations of the emulsion used made the observation uncertain. On June 30 of the same year the writer, using more contrasty plates (Seed 23's) found both Hβ and Hγ to have emission components, slightly brighter than the neighboring continuous spectrum in the case of Hβ and of nearly the same intensity as the continuous spectrum in the case of Hγ. Hδ was not certainly bright. Weak absorption borders and strong dark reversals of the emission characterized both Hβ and Hγ. The hydrogen lines of shorter wave-length were dark. The spectrogram of this date, together with others representative of the changes during the next five years, is reproduced in Volume II, page 36, of these *Publications*. Six further plates in 1911 showed no certain changes. In 1912, June 6, Merrill found Hα and Hβ indistinctly bright. At this critical period when the bright lines were disappearing as such, slight fluctuations perhaps and differences in photographic contrast certainly led to variations in the visibility of hydrogen emission on the spectrograms. On October 6, of the same year, the writer found no emission that stood out as such. Probably at this time the absorption borders seen in 1911 were not visible and the emission appeared not separated nor different in intensity from the continuous spectrum. There was, however, a noticeable increase in the intensity of the dark central reversals, which remained as the only clear features of the lines. In 1913, May 6 and June 9, Yerkes two prism plates show well defined hydrogen absorption in the photographic region but no certain emission except perhaps for a narrow slightly bright fringe outlining the absorption at Hβ on the second plate. The absence of definite bright line character in the photographic region continued on all further Ann Arbor plates, the dates of which were: 1915, December 9 and 14; 1916, January 6 and 22, August 21, October 3 and 10; 1917, October 1; 1918, October 2 and November 12; and many dates (twenty-one) in 1919, 1920 and 1921. The plates of 1916, January 6 and October 10 register the continuous spectrum in the Hα region but show no certain features of that line. Another in 1920, July 25, records the Hα region rather weakly but with a feature which might be interpreted as a dark Hα with narrow emission fringes. Strong Hα emission was certainly not present on these plates.

The dark hydrogen lines in the photographic region of the spectrum of f^1 Cygni, including the features which were formerly dark reversals of Hβ, Hγ, and Hδ, increased greatly in intensity between 1911 and 1916. Since then their intensity has remained nearly constant so far as observed at Ann Arbor except for a possible decrease indicated in November, 1918. At times bright fringes have been suspected on the edges of the dark lines both of hydrogen and helium since 1912, but nothing of a definite bright line character has been seen except perhaps a last trace in the case of the Hβ line on December 9, 1915. Narrow metallic emission lines, which were probably those which are frequently found in Class B spectra with strong hydrogen emission, were observed in f^1 Cygni's spectrum at Harvard in 1904. These had disappeared by 1911.

In an earlier description of the spectrum of f^1 Cygni in *Harvard Circular*, No. 98, based on two plates studied later by Miss Cannon, it is suggested that the emission lines of hydrogen may be variable in a short period. Possibly such variations, which have not been noted since could be attributed to exposure differences together with the observed excess of brightness of the component of shorter wave-length of the emission lines of hydrogen. Measures of the central absorption of the lines, Hβ, Hγ, and Hδ, on the Ann Arbor plates of 1911 to 1916 reveal a decrease of about one-half of an angstrom in the wave-lengths of these lines during this period. This may represent variable velocity but is probably a change of a different character, related to the fading out of the emission features.

The disappearance of the emission lines in the spectrum of f^1 Cygni seems to be quite as remarkable as in the case of Pleione but different in character. The hydrogen emission in Pleione appears to have vanished leav-

ing unreversed the wide dark lines on which it was superposed. In the case of f^1 Cygni the emission has decreased greatly in intensity and disappeared in Hδ, Hε, and Hζ. In Hβ and Hγ, where some emission is perhaps still present, the absorption borders that marked it off have disappeared leaving no line of demarcation between continuous spectrum and emission. On the other hand the dark double reversals (central absorption) have increased greatly in intensity and have become the outstanding features of the star's spectrum. Possibly the factors which caused the great luminosity in the gaseous envelope of f^1 Cygni have become restricted in effectiveness to the lower regions of the atmosphere.

Mu Centauri provides perhaps the most remarkable permanent (or semi-permanent) change yet observed in this connection, in the disappearance of the hydrogen emission lines in its spectrum. In the interval between 1890 and 1897, the Hβ emission line in this spectrum must have been one of the brightest lines of this type that has been observed in this group of stars, in the photographic region. And the other hydrogen lines were bright up to Hε. The extraordinary brightness of Hβ in this spectrum is well brought out in Plate II, at the end of *Harvard Annals*, Volume 28, where comparison can be made with the corresponding features in the light of γ Cassiopeiæ. In this same period McClean photographed the bright lines in this spectrum and published an enlargement showing them clearly in Volume XLII of the *Proceedings of the Royal Society*. On three-prism spectrograms made in Chile, in 1904, March 8, and 1905, January 14, April 8 and July 18, Wright found Hγ and Hδ bright and superposed on broad, dark lines. The width of Hγ was 2.6A and a fine dark reversal was strongly suspected on three plates. The radial velocity was not found to be certainly variable. In 1912, June 4, Miss Cannon finds that Hβ was not clearly seen, Hγ and Hδ dark. On July 12 of the same year the same observer finds that Hβ was very indistinct but with faintest traces of a bright line with borders. Hγ and Hδ were dark. In 1918, July 1, Perrine discovered the disappearance of all the hydrogen emission lines in the photographic region of this spectrum and the survival of dark lines. Apparently the strong emission of the nineties was distinct in 1904, evanescent in 1912, and non-existent in 1918.

Other stars from whose Class Bp spectra hydrogen emission lines have disappeared may be mentioned. On a photograph of the spectrum of J Velorum made in 1893, Hβ and Hγ were well marked emission lines superposed on wide dark absorption. Eleven plates in 1895, 1896, and 1899 gave no trace of emission. Photographs by Perrine in 1918 and others made at Arequipa in 1920 showed all lines dark. (*Harvard Circular* No. 224.)

The star, p Carinæ, had conspicuous hydrogen emission lines, Hβ and Hγ, on ten photographs taken between 1894 and 1897. Photographs taken by Perrine in 1918 and at Arequipa in June, 1920, show that these bright lines have disappeared. (See *Harvard Circular* No. 224).

The disappearance of emission at Hβ in the spectrum of H. R. 8731, noted by Frost, between 1913 and 1918, may or may not be of a permanent character. (*Astrophysical Journal*, Vol. 49, page 61). In the spectrum of this star observed at Harvard, only dark lines were photographed in 1904 and 1905, and in 1913 the Hβ line was not clearly seen and was certainly not present as a strong dark line. Frost found emission fringes or borders on either edge of and about as wide as dark Hβ and a similar border at Hγ in 1913 but dark lines only in the same (photographic) region in 1918. From studies of four spectrograms made on as many nights in October, 1918, J. S. Plaskett found the velocity of this star to be variable and the spectrum to be peculiar in having very broad hydrogen and helium lines of low contrast together with narrow sharp K and H lines giving smaller velocity range than the broad lines. The spectrum was considered possibly double and no bright lines or fringes were noted. Three excellent spectrograms of this star were secured at Ann Arbor in October, 1921. Broad hydrogen and helium absorption with sharp K and H were observed as noted by Plaskett but borders slightly brighter than the adjacent continuous spectrum were present on either edge of many if not all of the dark lines

from λ 5000 to Hζ, including K and H of calcium. These emission borders were narrow if accompanying narrow absorption and broad when associated with wide dark lines, in which latter case, as for example at Hβ, the outer limits of such borders were very difficult to establish. Fairly consistent measures of the widths of the parts of the Hβ line on the three Ann Arbor spectrograms gave 7.18A for the central absorption, 7.55A and 7.58A respectively for the emission fringes of smaller and of greater wave-length. Frost's values for the same quantities in 1913 were in order, 2.05A, 2.06A and 2.61A. If the fringes observed in 1921 were identifiable with those of 1913 they had changed greatly in width and intensity. Further, on the Ann Arbor plates sharp metallic lines were seen — notably λ4585, which was bordered by narrow emission fringes. Undoubtedly great changes have occurred in this spectrum since the Yerkes observations of 1913. The emission at Hβ and Hγ was not noted in 1918 and was certainly broader and less conspicuous in 1921 than in 1913. While the detection of emission fringes in 1921 is not conclusive evidence that they are reviving after a disappearance in 1918, all of the evidence taken together suggests that the variation in this case may be periodic, with the chance however that the narrow emission observed in 1913 will not be identified with that of 1921 but will be found to have been a non-recurring phenomenon. Further observations of this spectrum, and of the five other cases discussed above, should be made in order to continue the study of the nature of these changes.

The spectral changes described above, some of which are almost certainly progressive, seem to indicate that a Class B star may possess an atmosphere capable of producing strong emission lines, as compared with the continuous spectrum, though no such lines may be visible. And such strong emission lines may disappear without any change in the star's total light being noted. Apparently some kind of excitation, recognized in relatively few stars even in Class B and in these sometimes quite impermanent, is necessary to enable the radiations of the atmospheric envelopes of such Class B stars to betray themselves in visible emission lines. Possibly such excitation may be of the same nature as that which gives rise to luminosity in such objects as the Orion Nebula. If so it may be a relatively impermanent phenomenon whenever found in the atmospheres of stars having spectra of Class B. Or such excitation may be due to energy from within the star, in which case there may be long period or progressive changes in the rate of communication of such energy to the atmosphere. Again this excitation may be due to motion through nebulous matter of varying density with which these stars are so frequently and perhaps always associated. In as much as the well established progressive variations in the emission lines of Class Bp spectra have been in the direction of declining brightness, preference in a choice among the three possible sources of excitation referred to above may be directed to the first mentioned. But evidence of increasing brightness of hydrogen emission in Class Bp spectra has been noted and since this may be progressive in some cases it appears that we are not ready as yet to make any decision on this basis.

PLACE IN EVOLUTIONARY SEQUENCE[1]

In the discussion above several points have been brought out and others may be mentioned that may bear upon the question of the position of stars with Class Bp spectra in the evolutionary sequences.

1. These stars are known in some cases to be associated with or immersed in irregular nebulosity. Not infrequently they have nebulous attachments. Probably photography of these stars would multiply the number of known cases of such relationships.

2. Of these stars a relatively small number (perhaps two or three hundred) exist among the 222,000 stars of the *Henry Draper Catalogue*.

3. Probably nearly all of them have spectra in upper Class B.

4. They are relatively bright in their class so far as present discoveries go.

5. Some of these stars have spectra which are characterized by variations in emission lines which are apparently progressive. Such vari-

[1]Since this section was written a paper (*Popular Astronomy*, Vol. 28, p. 225) by Rev. Hector MacPherson covering some of the same points has been received.

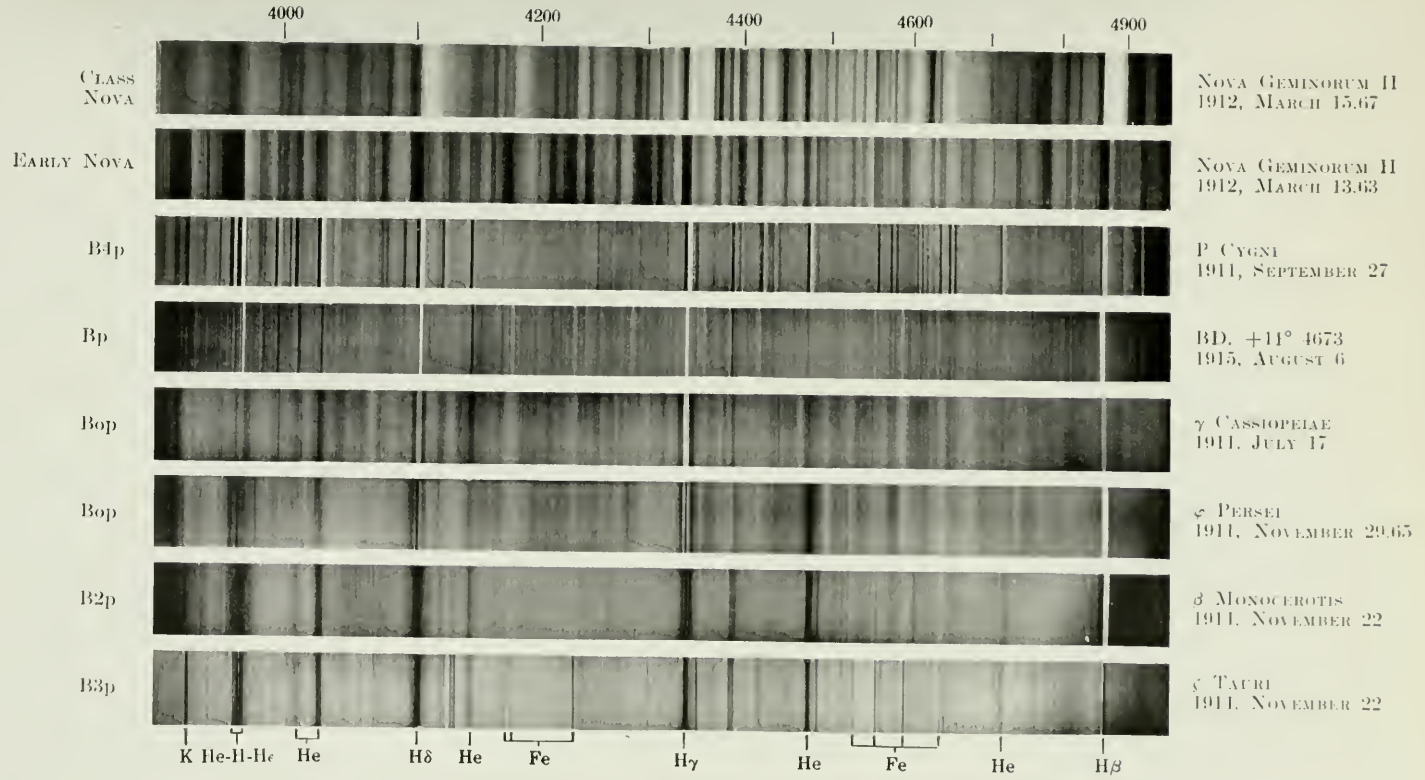


Plate B. Stellar Spectra Containing Emission Lines: A Series of Spectra Exhibiting Early Nova Types in Comparison with Representatives in Class Bp

ations are probably apart from those associated with binary or multiple character.

6. Progressive variations so far strongly indicated involve decline or effective disappearance of emission in hydrogen, helium, and metallic lines.

7. The radiation in the emission lines of hydrogen is a "low temperature phenomenon", with line intensity usually falling progressively with decreasing wave-length.

8. The presence of chromospheric bright lines of metals is frequently observed. These lines are strong in upper divisions of Class B and when they occur tend to be strong when the hydrogen lines are intense.

9. The residual velocities and τ-components of proper motion are shown on the basis of twenty-one of these stars to agree with Campbell's values for 225 stars with spectra of Class B. These stars with bright line spectra in Class B do not stand apart from other stars of the class in respect to residual motions so far as we know.

With these characteristics in mind discussion may be in order concerning the problem of the place of stars with Class Bp spectra in the proposed evolutionary sequences. Not that it can be asserted definitely that they are normal stars or, in case they do represent a normal stage of development, that they have a place in the evolutionary succession different from that of stars having similar spectra without visible emission lines. From some points of view they do appear connected with a particular stage in stellar history. Perhaps they represent unique stages in one or more lines of stellar development. Or their peculiarities may be due to a peculiar relation to the environment in which they are found. At any rate it seems insufficient to say that they are unique in their class only in the possession of extensive atmospheres. They have extensive atmospheres but, in addition, some kind of stimulus affects these atmospheres leading to visible emission lines that may be lacking in other stars apparently similarly constituted or that may be missing a few years later in the same star with the spectrum and possibly the atmosphere otherwise unchanged.

Stellar evolutionary theory is least convincing at the supposed points of contact of star with nebula. At this point the more prominent theories may be too strongly influenced by ideas coming from the Laplacian hypothesis. But such theories have prior claim to consideration. And in this connection studies of stars with Class Bp spectra may supply some evidence. Any facts concerning this stellar group may well be examined with this in mind, however reluctant one may be, in view of our limited knowledge in this domain on the physical side, to approach the subject of evolution near the nebular state.

A brief review of prominent current ideas on stellar evolution with possibly a few suggestions and interpretations may be in order at this point. The contributions of the various authorities to evolutionary theory and the sources of information in this connection are so well known that specific reference will not be made.

Probably many consider that the masses or clouds of non-shining or invisible matter of whose presence in considerable profusion within our stellar system we have convincing evidence, constitute the more strictly primordial or elemental state in which cosmic matter is known to exist. Some authorities feel that a strong case can be made for the hypothesis that the stars in general have evolved from the irregular nebulæ which had become luminous or luminescent before the stellar state had been reached. If nebulæ are of as low density as fairly definite lines of reasoning indicate, there would seem to be little or no probability of high temperature within them except perhaps in deep interiors where pressure of outlying parts prevents expansion. Heat of collision of meteoric particles might be a factor accounting for luminosity in an irregular nebula but it is not clear that this explanation is sufficiently far reaching nor that the emission resulting would be of bright line nebular character. In the history of a condensing dark nebula it is a question whether luminosity due to high temperature can obtain before densities greater than those usually ascribed to nebulæ have been reached. If so and if we exclude from consideration visible radiation not due to high temperature, the first light rays emitted by a condensing incipient star will be normally those characteristic of low temperature sources. The corresponding spectrum will be of Classes M or N.

Further condensation, according to Lane's Law, results in further increase in temperature with a change in spectrum upward in the Harvard sequence to a point depending chiefly on the mass of the star. Thereafter in a star so dense or otherwise altered that the effective specific heat of the mass is no longer negative, the temperature will fall and the spectrum will retrace the spectral sequence with inconspicuous but important differences from the characteristics shown when on the upgrade in the same spectral classes. Finally, in so far as we may be interested at present, the process comes to an end with invisibility in a star of relatively high density.

If we exclude all possibilities of stellar origin other than that so far considered we appear to make a stronger case if we can find a place for either planetary or luminous diffuse nebulæ or both in relation to this process of evolution.

But the highest spectral stage of development under this theory is perhaps more a matter of conjecture than any other question arising here. It has been suggested that a star, conceivably of great mass, might develop energy first by contraction only and later also by the release of subatomic stores, sufficient to cause it to ascend through the various stellar stages of visibility and finally to expand into a nebula. In this second nebular stage the object might be visible in part of its career but on the other hand the process of expansion might reduce the temperature below that of incandescence before the nebular state could be reached. Indeed it seems more than probable that the expansion and cooling of a gaseous star, whose specific heat is negative, under the release of subatomic energy would quickly check this supply thus setting up a balance that would always preclude return to the nebular state except perhaps in a few stars of excessive mass. Again it may be suggested that the disintegration of stars by emission of electrified particles, such as those which come in important amounts from the sun, might lead to the formation of visible nebulæ. Probably no one would consider these suggestions adequate to account for visible nebulæ as we find them. It seems more reasonable to suppose that many visible nebulæ are luminous because of the influence on them of stars situated within or near them. We cannot say that every visible nebula has its stellar companion or companions but many nebulæ undoubtedly enclose visible stars and, wherever there is a great nebulous region, stars with Class B and other "high temperature" spectra are abnormally plentiful. Our own sun, of relatively low surface brightness, excites luminosity in comets, our own atmosphere, and the corona and illuminates to the point of visibility such pulverulent objects as distant comets, the zodiacal light, and the gauze ring of Saturn. Possibly no known solar or colder star could excite surrounding nebulosity to luminosity visible from the earth. But a high temperature, high luminosity blue star could conceivably render visible a great volume of nebulous matter about it both by illumination and by excitation to luminosity. Slipher has found convincing evidence of star light due to reflection or to resonance in the nebulosity about the Pleiades, about Rho Ophiuchi, and in the outlying regions in Orion. Usually these "reflexion nebulæ" are associated with and probably are parts of dark "absorption nebulæ" whose presence is recognized by peculiar variations in the density of the stellar floor. In exceptional cases the reflection spectrum of a nebula contains bright lines due to the illuminating star. But the chief source of bright line radiation under this hypothesis, in a nebula like the Orion Nebula, would be excitation due to influences coming from the star or stars. Emission of electrified particles and rays of short wave-length, ionization facilitating electrical discharges, the latter arising from potential differences associated with motion due in part to the star's gravitational field — all these and other influences must be factors making for luminosity in nebulous matter about a massive, high temperature, high luminosity star.

But even though the visibility of some irregular nebulæ be accounted for in this way it is doubtful whether the luminosity of planetaries would find a similar explanation. Many of them appear to have no stellar nucleus. Their origin might be traced to expansive forces in a star overcharged with released subatomic energy. But our knowledge of the changes in Novæ suggests strongly that the 150 planetary nebulæ in our catalogue are the descendents of "new stars" of the past, most of which were brighter perhaps

than any of which we have record. Their origin appears to have been cataclysmic, possibly due to collision. They follow then a sudden transformation of molar energy into heat as the result of which a star in any normal evolutionary stage may be converted suddenly into a nebulous state. That planetaries are initially hot by the very nature of their genesis and that they develop first into stars with Class O spectra and then down the spectral sequence there is strong reason to believe.

Thus we may account with some plausibility for the various types of celestial objects which theory has associated with stellar evolution, though possibly not for every known member of our sidereal system. But there are some to whom the explanations given above to account for the visibility of irregular nebulæ appear unconvincing. They incline to the belief that irregular nebulæ are not dependent on stellar influence for their bright line radiations and that a nebula becomes luminous through excitation generated within itself before it reaches the stellar state. That such excitation is initially thermal seems very doubtful. If it were we would expect to find low temperature nebulæ. And in such objects why should the Hα line not occur with greater relative intensity, giving us visually red objects, perhaps, like the chromosphere? Electrical discharge may account for the initial luminosity of an irregular nebula, or it may be luminescence, and as such may from the beginning of the objects luminous history produce radiations of "high temperature" quality, such as those with which we are familiar in the Orion Nebula. As such an object contracts toward stellar densities, thermal radiation may replace emission due to electrical discharge or to luminescence. Contraction giving rise to increased temperature would at the same time entail increased density unfavorable to electrical discharge. Thermal excitation would replace electrical and a star might thus develop from a luminous nebula without passing through a stage in which red light would predominate. The last evidences of radiation due to electrical discharge might be found in the atmospheres of such newly formed stars. These bodies would then progress down the scale corresponding to the spectral sequence, the surviving bright line radiation disappearing early in their history as stars.

Our interest in this discussion lies primarily with the Class B spectra and especially with those having bright lines. We may consider as possibilities then that stars with Class B spectra develop in at least three ways in accordance with the discussion of the last few paragraphs: (1) From dark nebulæ upward through the spectral sequence beginning with M and N; (2) From planetaries through Class O to Class B; (3) From luminous irregular nebulæ perhaps directly to Class B.

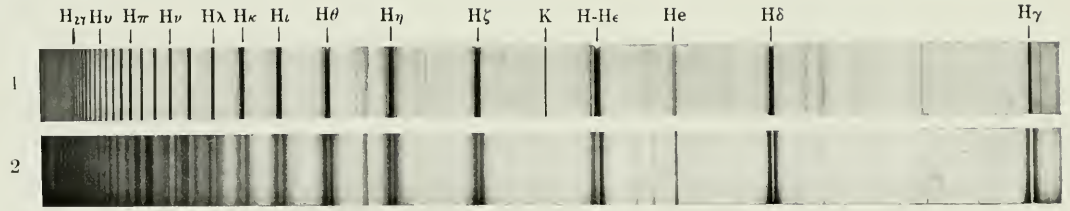
But so far as stars having Class B spectra with bright lines (Class Bp) are concerned there seems to be some evidence to indicate that planetary nebulæ are not their progenitors, and thus that the second of the above possibilities is not important. The spectra of the stellar nuclei in planetary nebulæ (Class O spectra) contain in their earliest stages broad bright lines of hydrogen and helium and notably bright bands in the region, λ 4600 to λ 4700. Hydrogen and helium lines broaden and fade as spectra proceed along the subdivisions of Class O while the bright bands around λ 4650, which are in part due to helium, continue for a time relatively strong. In Class Od all hydrogen and helium lines have become dark; the additional series of helium is at a maximum of strength as absorption lines; only the two bands near λ 4650 are bright. In Class Oe these two bright bands are less intense; all other lines are dark; the additional helium lines are less intense while the characteristic Class B lines of helium are nearly as numerous and well marked as in Class B spectra; other dark Class B lines are coming in. In Class Oe5, with spectra intermediate between Classes Oe and B, with few if any exceptions, no bright lines are found. When stars have developed from planetary nebulæ or Class O stars to the stage associated with Class Oe5 spectra, bright line radiation in their light appears to be invisible. The next step appears to be normally the emission of a dark line Class B spectrum and not one containing the bright lines of hydrogen and helium that faded from such a spectrum, on this hypothesis of development, in the earlier subdivisions of Class O. Though the subdivisions of Class O may correspond to more than one

evolutionary sequence, it is hardly conceivable that many Class Bp spectra are emitted by stars which have developed in or from planetary nebulæ.

In addition to qualitative spectral indications the wide disparity in the average residual velocities of planetary nebulæ and that of stars with Class Bp spectra, argues against a genetic relationship not far removed. And the difference between the average brightnesses of these two classes of objects holds them apart. Stars with Class Bp spectra derived from stars with Class O spectra would be faint and possibly fast moving, not relatively bright and slow. About 150 planetaries are known. Thus it appears improbable that many if any of the 143 known stars with Class Bp spectra have originated from planetary nebulæ, which average much fainter, even if such nebulæ were more numerous in the past.

There is perhaps a stronger chance that stars having Class Bp spectra have developed from objects of Class M and Class N in accordance with the first possibility mentioned above. Residual velocity data do not present difficulties here. And the association of these stars with visible irregular nebulæ when it exists may be due to the influence of these stars on such objects. These stars are relatively luminous in their class. In view of their extensive atmospheres it seems improbable that this is due to greater surface brightness. It is due more probably to greater mass or greater size (lower density) on the average in their class, possibly to both. A body attaining Class B temperatures at relatively low densities would be presumably of relatively great mass according to this rationale. A greater mass would in general lead to higher maximum temperature in the development of a star, and possibly to other conditions, such as relatively low density for a star of the class and extensive gaseous envelopes, favorable to atmospheric luminosity. If there are lower density Class B stars we might expect a related stage next following to be that of a still hotter Class Oe5 star with bright lines of hydrogen and helium. Such has apparently not been found. Again if stars with Class Bp spectra do develop in this way we might expect cases to be found in which the bright lines are definitely growing stronger. Cases are known in which all of the bright lines have disappeared as such from the spectrum. Though no certain cases are known in which emission lines have come in permanently or semi-permanently or have grown progressively stronger in Class Bp spectra, indications of increased strength have been found.

Some acceptability may be found for the third possibility mentioned above, that stars with Class Bp spectra represent the earliest stage in the life of bodies which have developed by condensation in self-luminous irregular nebulæ. This is an old theory but one which has been kept alive awaiting the verdict of time. In the first place the relation of position between these two classes of bodies is a favorable point. Though stars with Class Bp spectra are seldom if ever associated with planetary nebulæ, so far as known, they are found in association with or immersed in visible irregular nebulosity as in the cases of Gamma Cassiopeiæ, Omega Orionis, and 25 Orionis. Undoubtedly other and perhaps many stars of this group would be found related to luminous nebulæ if a photographic survey were made with this in view. Again, residual velocities of these stars so far as known accord with the relationship suggested. To collect about them an atmosphere great enough to emit visible bright lines for some time after the stellar state has been reached relatively great mass may be necessary. This condition combined with the low density of newly formed stars would mean great volume and hence the observed great brightness in their class. In the extensive atmospheres of such stars the self-luminosity would be carried over from the nebulous state. If so we would expect that this luminosity would disappear as such in time leaving a normal Class B spectrum. Our observations register such disappearances and show moreover that, whereas an extensive atmosphere may be a necessary concomitant of visible emission lines, it is not a sufficient one. Some kind of excitation, effectively evanescent in some stars, is also necessary. Such excitation may continue until the spectrum of the lower absorbing layers has advanced well into Class B but no longer. Increasing density perhaps is unfavorable to longer continuance. That the hydrogen lines resemble in relative intensity those in the vacuum tube spectrum is in keeping with the theory of electrical origin in a low density medium. The great-



1. ζ Tauri. 1914, November 22.
2. 11 Camelopardalis. 1916, March 2

Plate C. Spectra of Zeta Tauri and 11 Camelopardalis

er intensity of Hα in these spectra as compared with that in the spectrum of the Orion Nebula may be related to the last phases of the luminous state. In this connection the relatively marked decrease in the intensity of the hydrogen lines with decreasing wave-length as they existed in the spectrum of Mu Centauri before they faded from the light of that star is especially noteworthy.

The small number of stars with Class Bp spectra indicates either that few stars develop bright line characteristics in this class or that they pass through the bright line phase quickly. If all Class B stars pass through this phase the rapidity of change of spectral characteristics during the bright line phase might be greater than our studies lead us to believe. It seems more reasonable to conclude that stars having Class B spectra with visible bright lines belong to a special class which may have developed from irregular visible nebulæ. It is true though that evidence, as strong as confidence demands, of a close genetic relationship between self-luminous irregular nebulæ and stars with Class Bp spectra is not found in several important directions. More cases of close association of such stars with visible nebulæ would help sustain the relation and should be sought for. Knowledge of the existence of objects with spectra clearly intermediate in type between Classes Pb and Bp is also desirable. Objection to mention of P Cygni in this connection would perhaps be well taken but we may cite the Class B5p component of Beta Lyræ and Gamma Cassiopeiæ with bright D_3. These stars have helium as well as hydrogen and iron emission. Nebulium would appear never and bright helium lines seldom to survive the change from nebular to Class Bp spectra, while enhanced iron emission comes in. It is possible but not probable that spectra illustrating this supposed transition from Class Pb to Class Bp will be found.

In the meantime attention has been directed by Merrill and others to another explanation of the occurrence of stars with Class Bp spectra. In the spectra of novæ the earliest bright line stage is marked by the presence of the same chromospheric emission lines that are found in Class Bp spectra with some others added, suggesting a more intense condition in the novæ. In the spectrum of Eta Carinæ also an extreme Class Bp condition is found. It seems probable that an accentuation of the chromospheric emission in typical Class Bp spectra would result first in a spectrum of P Cygni type like B. D. $+11^\circ$ 4673, then in the present Eta Carinæ spectrum, and finally in that of an early nova. It seems logical therefore to consider the possibility that the same stimulus in responsible for the bright line characteristics in novæ, Eta Carinæ, B. D. $+11^\circ$ 4673, and Class Bp spectra in different degrees, a stimulus which usually excites only strong chromospheric radiation in the three last named spectra but which goes much further at times in Eta Carina and at present in P Cygni and commonly in the later stages of a nova. Many think that novæ and Eta Carinæ owe their surface stimulation, variable as it is, to motion through a nebula; and the evidence is strong that such is the case. If we have a few cases of violent nebular collision why not a number of cases of a milder character? It seems possible that bright line spectra in Class B are to be accounted for as the result of a less violent application of the same stimulus. We should expect to find such stars in Class B both because it is stars with such spectra which flourish in nebulous regions and because the same stimulus which gives rise to emission lines would tend also to modify the spectral class upward toward the top of the sequence. The nebula in any case may be visible or invisible. Possibly these stars are bright in their class because relatively massive larger stars are more effective in bringing down nebulous material onto their surfaces. It will not be necessarily unfavorable to this hypothesis if in many cases no visible nebulosity is found connected with them. On this hypothesis spectral variability, especially in the bright lines, would be anticipated, due for example to varying density in the stimulating nebula. In this connection it may be only a coincidence that the well-established progressive changes have been those of declining brightness. And it is not to be overlooked that indications of increasing brightness of emission lines have been found.

Effects due to motion of stars through resisting media in space may be contributing factors influencing the character of stellar spectra, as suggested by Perrine. At any rate the pecu-

liarities observed in the spectra of Class Bp are perhaps best accounted for in most cases at least on the assumption of motion through a resisting medium or, in other words, a nebula.

In the accompanying illustration, Plate B, spectra of Nova Cygni II, P Cygni and the prevailing Class Bp types are arranged in a provisional sequence showing resemblances and possible relationships.

SUMMARY

The number of stars brighter than 8.5 and 9.0 magnitude in the group of stars having bright line spectra in Class B is probably more than two hundred. At present, early in 1921, 143 are known to the writer, including those that have lost their emission lines.

In former classifications spectra in this group assigned erroneously to subdivisions of Class A and to Class Fo influenced generalizations regarding these stars. In the new classifications of the *Henry Draper Catalogue* covering, as received to date, the first twelve hours in right ascension, no object in this group remains outside of the limits, Bo to B8, and only two outside of the limits, Bo to B5.

Stars with bright line spectra in Class Bp, so far discovered, are relatively bright in their class. Probably this is due to great volume associated with great mass or low density or both.

These stars appear not to stand apart from others of Class B in respect to residual motions.

Three stars in this group, Pleione, f^1 Cygni, and μ Centauri, have lost their former strong bright hydrogen lines, as such. Two other stars, J Velorum and p Carinæ, are probably in the same category. No well-established progressive variations in the emission lines of Class Bp spectra have been in the direction of increasing brightness, though indications of such changes have been found.

A review of a number of facts relative to this group of stars indicates that it is not sufficient to say that these objects are unique only in the possession of exceptionally extensive atmospheres. In discussing possible unique relations of Class Bp stars to proposed evolutionary schemes it is suggested that they may develop in at least three ways:

1. From dark nebulæ upward through the spectral sequence.

2. From luminous irregular nebulæ perhaps directly.

3. From planetaries through Class O.

It is further suggested, as a plausible theory, that the emission lines in these stars may be due to the action of resisting media through which they are in motion, and that in connection with the origin and development of such stars, with the possible exception of great average mass, there is no other unique evolutionary factor.

Ann Arbor, Michigan, 1921.

THE SPECTRUM OF κ DRACONIS

STUDIES OF CLASS B STELLAR SPECTRA CONTAINING EMISSION LINES

By ROBERT H. BAKER

The spectrum of κ Draconis (1900.0, $\alpha = 12^h\ 29^m.2$; $\delta = +70^\circ\ 20'$; H. R. mag. 3.88) is of Class B5p. As early as 1890, Pickering detected bright lines in the spectrum of this star. In the *Harvard Annals*, Volume 28, page 104, Miss Maury's description is substantially as follows: The spectrum resembles in some degree that of γ Cassiopeiæ. The lines are extremely wide. A bright band lies centrally on the wide dark band Hβ. The lines Hγ, Hδ, Hϵ, and, perhaps, Hζ appear hazily triple. The Orion lines are perhaps double.

Merrill, in *Lick Observatory Bulletin*, Volume 7, page 162, assigns this star to his γ Cassiopeiæ group whose hydrogen emission lines are strong. On spectrograms of 1912 he finds "Hβ double bright on absorption, Hγ hazily double bright on absorption, Hα bright, D_3 faint broad absorption."

This star has been under observation at the Detroit Observatory since 1912 in connection with Professor Curtiss' program of Class B spectra containing emission lines. The series of plates was generously turned over to the writer for examination and measurement during his stay in Ann Arbor in the summer of 1919.

As it appears on the Ann Arbor plates, the outstanding feature of the spectrum is the Huggins series of hydrogen. Broad emission lines are centrally superposed on broader absorption, while narrow absorption lines appear nearly central upon the emission. The other lines are generally broad and not well defined; they include the helium lines $\lambda\lambda$ 3970, 4026, 4144, 4388 and 4471, the carbon line λ 4267 and the magnesium line λ 4481. Faint emission certainly divides these lines on some of the plates. The K line of calcium is narrow and poorly defined. Other faint, narrow absorption lines are occasionally detected, and their reality appears to be confirmed by Mr. Barrett's notes on κ Draconis, which Professor Frost has kindly sent in a letter. On examining a few plates of this star taken at the Yerkes Observatory between 1902 and 1911, Barrett finds narrow absorption at $\lambda\lambda$ 4549, 4552, 4572 and 4590.

The present study of κ Draconis is based on the writer's measurements of 96 spectrograms made by Professor Curtiss and his assistants with the single prism spectrograph of the Detroit Observatory. The plates are either Seed 23 or lantern slide. As the measurement of the plates proceeded, it became evident that the behavior of the broad emission and absorption is unlike that of the narrow absorption lines. In Table 1, I have therefore separated the velocities from the two sources; columns 5, 9, and 10 contain the velocities derived from the broad lines, the narrow hydrogen absorption, and the K line respectively.

THE BROAD ABSORPTION AND EMISSION LINES

Only two broad lines are measurable often enough to be of value, namely, the hydrogen emission at λ 4861.527 and the helium absorption at λ 4471.68. On 47 plates where both lines were measured, the average difference in the velocities derived from the two is

Mean velocity difference $(4861 - 4471) = +8$km.

In order to make the results homogeneous, a correction of +8 km. is applied to all the velocities from the helium line.

The mean velocities, in the fifth column of Table 1, are variable. After a number of trials the period of the variation was found to be 8.986 days. Having established the binary character of the star, we may now determine the orbit.

TABLE 1

ANN ARBOR OBSERVATIONS OF KAPPA DRACONIS

PLATE NO. (1)	DATE G. M. T. (2)	PHASE (3)	4471 ABS. AND 4861 EM. NO. OF LINES (4)	4471 ABS. AND 4861 EM. MEAN VELOCITY (5)	4471 ABS. AND 4861 EM. O–C (6)	NARROW H ABSORPTION NO. OF LINES (7)	NARROW H ABSORPTION WEIGHT (8)	NARROW H ABSORPTION MEAN VELOCITY (9)	3933 (K) VELOCITY (10)
	d	d		km.	km.			km.	km.
515	1912 May 8.62	0.92	1	+23	+13	3	4	−10	
516	8.64	0.94	1	+24	+14	4	4½	−12	
539	14.68	6.98	1	−17	− 1	3	4	− 6	
540	14.71	7.01	2	−21	− 5	2	1½	− 8	
559	17.66	0.97	1	+ 9	− 1	2	2½	−13	
571	22.62	5.93	1	−21	− 1	3	3	−17	
572	22.64	5.95	1	− 5	+15				
577	23.70	7.01	1	−32	−16	2	2	−16	
609	30.64	4.97	1	−29	−10	4	4	+ 9	
639	June 2.64	7.97				2	2	−14	
673	6.66	3.00	1	+ 2	+10	2	2	− 2	
692	8.66	5.00	2	−13	+ 6	3	3	+10	
1639	1913 March 31.77	4.57	1	− 7	+10	4	4	−16	
1640	31.80	4.60	2	−21	− 4	3	3	− 6	
1652	5.78	0.60	1	+ 5	− 6	3	5	− 4	
1657	6.70	1.52	2	− 2	− 8	2	3	+ 2	
1658	6.71	1.53				2	2	−11	
1681	13.66	8.48	2	+24	+22	2	3	+ 3	− 6
1682	13.69	8.51	1	− 3	− 5	1	2	+ 7	
1710	16.71	2.54	1	+12	+16	2	3	+ 5	
1722	19.67	5.50	1	−38	−18	2	2	− 2	
1723	19.69	5.53	1	−10	+10				
1733	20.64	6.47	1	−10	+ 9	1	1	− 2	−19
1734	20.65	6.48	1	− 9	+10	1	½	+24	
1746	23.68	0.53	1	+21	+10	2	2½	+13	
1806	May 1.70	8.55	1	+ 3	− 9	2	4	+ 2	
1820	3.65	1.51	2	− 2	− 8	3	3	+13	− 7
1821	3.66	1.52	2	−11	−17	4	4	+ 4	
1841	7.64	5.50	1	+ 2	+22	3	2½	+ 8	
1842	7.68	5.54	2	−23	− 3	4	5	+18	
1859	10.66	8.52	2	+20	+17	2	1½	0	
1860	10.68	8.54	2	−18	−21				
1880	18.63	7.50	2	−18	− 6	2	2	−18	−18
1881	18.64	7.51				2	3	+ 1	
1905	31.67	2.57	1	−13	− 8	3	4	− 5	
1906	31.68	2.58				2	2½	+ 1	
1964	June 8.68	1.60	2	+ 6	+ 1	3	3½	− 7	
1965	8.69	1.61	1	+ 4	− 1	2	2	+ 9	
2012	14.66	7.58	1	−28	−17	1	½	+ 2	
2013	14.68	7.60	1	−16	− 5	1	½	−10	

TABLE I

ANN ARBOR OBSERVATIONS OF KAPPA DRACONIS — CONTINUED

PLATE NO. (1)	DATE G. M. T. (2)	PHASE (3)	4471 ABS. AND 4861 EM. NO. OF LINES (4)	4471 ABS. AND 4861 EM. MEAN VELOCITY (5)	4471 ABS. AND 4861 EM. O-C (6)	NARROW H ABSORPTION NO. OF LINES (7)	NARROW H ABSORPTION WEIGHT (8)	NARROW H ABSORPTION MEAN VELOCITY (9)	3933 (K) VELOCITY (10)
	d	d		km.	km.			km.	km.
2661	1914 March 20.72	8.07	2	−16	−11	2	1½	−17	
2662	20.76	8.11	1	− 8	− 4	1	1	−11	
2731	May 5.64	0.07	2	− 2	−11	2	3	+10	
2732	5.67	0.10	2	+ 4	− 5	2	3	+ 9	
2766	15.66	1.11	1	+ 2	− 7	3	3	+13	
2771	17.65	3.10				2	4	− 5	
2829	June 9.67	8.15	2	−11	− 7	2	3	− 2	
2843	16.66	6.15	2	−24	− 4	3	4	+ 6	− 7
3120	1915 Feb. 27.80	1.70	1	+31	+27	2	4	+12	
3137	Mar. 9.78	2.69	2	+10	+16	4	5½	+12	
3149	17.80	1.72	1	+32	+28	2	2	+17	+12
3154	23.77	7.69	2	−14	− 4	2	2	− 8	− 9
3165	30.78	5.72	1	−35	−15	2	3	+ 3	
3174	Apr. 7.77	4.72	1	−15	+ 3	3	5	+ 5	− 1
3178	13.78	1.75	1	−16	−19	2	3	+12	−10
3182	14.72	2.69	2	−13	− 7	2	3	− 3	
3196	May 5.68	5.67	1	−12	+ 8	2	1½	+19	
3204	10.70	1.71				3	4½	+18	
3207	11.69	2.70	2	−18	−12	2	3	+ 3	
3211	12.67	3.68				3	5	+10	
3215	17.63	8.64	2	+16	+11	2	4	− 8	+ 8
3221	18.60	0.62	2	− 4	−15	3	5	+ 2	+ 7
3239	31.65	4.69	2	−18	0	2	3	− 8	−19
3248	June 5.62	0.67	2	+13	+ 2	2	3	+19	
3256	12.62	7.67	1	+ 1	+11	2	3	+ 4	
3270	23.70	0.78	2	+17	+ 6	2	3	+ 5	
3440	1916 Feb. 29.79	0.26	2	+26	+15	2	2	+ 9	
3443	March 2.77	2.24	1	+ 1	+ 3	2	2	− 2	
3453	15.77	6.25	2	−22	− 3	3	4	− 2	
3462	23.70	5.19	1	−21	− 2				
3473	April 6.74	1.27	2	−12	−20	4	6	+ 4	
3474	6.77	1.30	2	+21	+13	4	6	− 6	
3496	17.71	3.25	2	−32	−21	3	5	−13	
3497	17.75	3.29	2	−28	−17	4	6	−10	−30
3498	27.73	4.28	2	+ 4	+20	4	5	+12	
3499	27.75	4.30	2	− 4	+12	4	6	+ 2	−22
4090	1918 March 15.76	8.38	2	+16	+15	3	3	+13	
5002	26.68	1.33				2	3	+10	
5173	1919 May 5.67	1.95	2	+20	+19	2	3	+ 5	
5174	5.70	1.98	1	+ 5	+ 4	1	½	+ 7	

TABLE 1

ANN ARBOR OBSERVATIONS OF KAPPA DRACONIS — CONTINUED

PLATE NO.	DATE G. M. T.	PHASE	4471 ABS. AND 4861 EM.			NARROW H ABSORPTION			3933 (K)
			NO. OF LINES	MEAN VELOCITY	O–C	NO. OF LINES	WEIGHT	MEAN VELOCITY	VELOCITY
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	d	d		km.	km.			km.	km.
5201	1919 July 16.62	2.01	1	+ 2	+ 1	3	4	+13	+ 4
5202	16.64	2.03	2	+ 2	+ 1	3	5	+18	−10
5203	16.66	2.05	2	+11	+10	2	2	− 1	
5207	17.62	3.01	1	−16	− 8	2	3	+ 9	
5208	17.64	3.03				1	1	+ 2	
5209	17.65	3.04	2	−16	− 7	3	5	+12	−20
5213	18.65	4.04	2	−40	−25	2	3	+15	− 5
5214	18.68	4.07	2	− 9	+ 6	3	4	+ 3	− 9
5215	18.70	4.09	2	−24	− 9	2	4	+ 4	0
5218	22.61	8.00				4	5	+11	+ 8
5219	22.63	8.02	2	−16	−10	4	4½	+16	− 9
5220	22.64	8.03	2	+11	+17	3	5	+15	
5231	28.66	5.06	2	−22	− 3	2	3	+ 4	+22
5232	29.61	6.01	2	−14	+ 6	2	3	− 8	
5233	29.65	6.05	2	−18	+ 2	2	3	+ 8	
5234	29.67	6.07	1	− 5	+15	2	3	−11	

In Table 2 the 86 observed velocities are assembled with regard to phase into sixteen normal places. As a first approximation to the elements of the orbit I have chosen the following:

PRELIMINARY ELEMENTS

$P = 8.986$ days
$\mu = 40°.0623$
$K = 17$ km.
$e = 0.30$
$\omega = 350°$
$\gamma = -6$ km.
$T = 1915$ April 21.32 G. M. T.

The residuals for the normal places from the velocity curve which represents these elements are now subjected to a least squares solution. Employing Schlesinger's formulæ and notation we derive the normal equations:

$$\begin{aligned} 12.100\Gamma - 2.474\kappa + 0.981\pi + 5.321\epsilon + 0.224\tau &= -14.2 \\ 6.064\kappa - 0.020\pi - 0.090\epsilon + 0.094\tau &= -1.3 \\ + 6.036\pi + 0.458\epsilon + 3.482\tau &= +14.9 \\ + 3.831\epsilon + 0.082\tau &= -3.0 \\ + 2.164\tau &= +7.8 \end{aligned}$$

The solution of these equations gives the corrections to the preliminary elements.

CORRECTIONS

$\Delta K = -1.3$ km.
$\Delta e = -0.07$
$\Delta\omega = -24°$
$\Delta\gamma = -1.2$ km.
$\Delta T = -0.30$ days

TABLE 2

NORMAL PLACES

NO.	PHASE	LIMITS OF PHASE		WEIGHT	VELOCITY	O − C
	d	d	d		km.	km.
1	0.32	0.07 to 0.62		1.0	+ 7.4	− 3.6
2	0.82	0.67	0.97	0.7	+16.6	+ 5.8
3	1 40	1.11	1.52	1.0	− 0.9	− 7.3
4	1.66	1.60	1.75	0.5	+10.5	+ 6.6
5	2.04	1.95	2.24	0.8	+ 8.2	+ 8.1
6	2.66	2.54	2.70	0.7	− 5.4	+ 0.3
7	3.15	3.00	3.29	0.7	−20.8	−11.2
8	4.16	4.04	4.30	1.0	−14.6	+ 1.2
9	4.65	4.57	4.72	0.5	−15.7	+ 2.1
10	5.05	4.97	5.19	0.5	−20.0	− 1.0
11	5.57	5.50	5.72	0.7	−20.0	− 0.1
12	6.08	5.93	6.25	1.0	−16.8	+ 3.0
13	6.82	6.47	7.01	0.5	−18.3	− 0.9
14	7.61	7.50	7.69	0.7	−15.3	− 4.6
15	8.07	8.02	8.15	0.8	− 8.0	− 3.5
16	8.51	8.38	8.64	1.0	+ 9.7	+ 7.3

The final elements are therefore:

FINAL ELEMENTS

$P = 8.986$ days
$\mu = 40°.0623$
$K = 15.7$ km. ± 1.8 km.
$e = 0.23 \pm 0.08$
$\omega = 326° \pm 21°$
$\gamma = -7.2$ km.
$T = 1915$ April 21.02 ± 0.44 days
$a \sin i = 1{,}890{,}000$ km.

The probable error of a normal place, weight unity, is ±3.6 km; the probable error of a single place on which both lines were measured is ±8.2 km. The latter value is obtained from the plate residuals scaled from the final curve, which are found in the sixth column of Table I. These errors are not surprising, in view of the small number and indefinite character of the available lines.

THE NARROW HYDROGEN ABSORPTION LINES

Almost centrally placed against the broad emission, the narrow hydrogen lines are fairly well defined. The five lines which were measured and their wave-lengths which were used in reducing the measures are as follows:

Hζ = λ3889.15
Hε = 3970.177
Hδ = 4101.92
Hγ = 4340.634
Hβ = 4861.527

On comparing the velocities from Hγ with those from the other lines, I find the following mean differences:

	COMPS.	
Hζ − Hγ = +2.4 km.	9	Corr. to Hζ = −2 km.
Hε − Hγ = −4.8 km.	24	Corr. to Hε = +5 km.
Hδ − Hγ = −3.4 km.	74	Corr. to Hδ = +3 km.
Hβ − Hγ = −7.9 km.	21	Corr. to Hβ = +8 km.

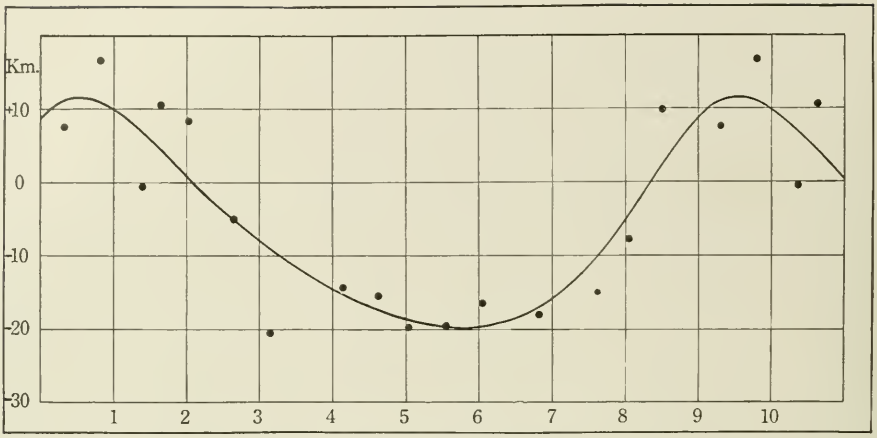


FIG. II. VELOCITY CURVE FROM BROAD EMISSION AND ABSORPTION LINES OF KAPPA DRACONIS

For the sake of homogeneity I have applied the above corrections to the separate velocities derived from these lines. The mean of the velocities so corrected is given for each plate in the ninth column of the Table 1 of Observations. The weight, in the preceding column, is the sum of weights assigned to the different lines at the time of measurement.

The velocities from the narrow hydrogen lines do not share the short period variation of those from the broad lines. Moreover, so far as I can determine, they show no evidence of variation in any period of short duration. It remains to inquire whether they show any variation at all. In Table 3 I have assembled the means by years of the uncorrected velocities from the separate lines. It is at once evident that the narrow hydrogen lines have shifted toward the region of greater wave-lengths in the interval from 1912 to 1919 by an amount corresponding to a positive

TABLE 3

MEAN VELOCITIES FROM THE NARROW HYDROGEN LINES

YEAR	Hζ		Hε		Hδ		Hγ		Hβ	
	NO. LINES	VEL.	NO. LINES	VEL.	NO. LINES	VEL.	NO. LINES	VEL.	NO. LINES	VEL.
		km.		km.		km.		km.		km.
1912			2	+1.3	9	−9.5	11	−5.9	8	−20.0
1913			4	0.0	21	−2.9	24	−0.5	10	− 4.1
1914					7	+2.3	8	−0.7	2	− 2.0
1915	2	+14.7	5	+2.0	17	+2.8	17	+6.1	1	− 8.0
1916	6	− 5.2	7	−5.2	9	−3.1	8	−1.0		
1918–19	3	+17.3	10	+8.3	19	+3.2	16	+8.6		

velocity increase of more than 10 km. a second. In 1916 the lines swung back almost to their original positions, but in 1919 they had regained the lost ground and had moved still farther toward the red end of the spectrum.

As Table 3 shows, no velocities were derived from Hζ during the first three years, and there are none from Hβ during the latter half of the interval. The explanation in the first case is that Hζ became suitable for measurement after the installation of a more transparent prism, a change described by Professors Hussey and Curtiss in Volume I, page 77, of these *Publications*. But the change of prisms appears to have no connection with the visibility of Hβ, which gradually diminished until its disappearance in 1915. In Table 3 we find that Hβ was measured in 1912 nearly as often as Hγ and Hδ, in 1913 half as often, and in 1914 only one-quarter as often. Diminishing width of the narrow Hβ accompanied diminishing intensity. In Table 4 we see it had shrunk in 1914 to only half its width in 1912. It is interesting to notice that the Hγ line shows no appreciable variation in width during the entire period of time covered by the Ann Arbor plates.

The history of the narrow absorption at Hβ antedating the Ann Arbor observations is not clear. Miss Maury did not detect it in the early Harvard spectra of κ Draconis, although she saw the other hydrogen absorption lines "hazily triple." Through the kindness of Professor Frost I have been able to examine the five spectrograms of this star taken at the Yerkes Observatory in the years 1902, 1904 and 1911. On Plate III B 287, 1902 February 3, absorption clearly divides the emission at Hβ. It is not visible on the other four plates. Dr. Merrill (loc. cit.) found narrow Hβ on his plate of 1912 February 26, but he failed to see it on the Lick Observatory plates of the previous year. While the available evidence might be taken to mean that the line in question has been visible at intervals, perhaps at some phase of the fluctuating narrow hydrogen lines, it seems to me that this construction would have insecure foundation at present, since the dispersion and grain of the early plates were not favorable for the detection of detail in the Hβ region.

THE K LINE

The narrow calcium absorption at λ 3933.825 is faint and poorly defined. In addition, it is confused with the faint, broad helium lines in this part of the spectrum. Ordinarily it would not be measured. However, because of the interest that is attached to the behavior of narrow calcium lines in spectra of this class and especially because of the presence and peculiar

TABLE 4

WIDTHS OF EMISSION AND NARROW ABSORPTION AT Hγ AND Hβ

YEAR	Hγ EM		Hγ ABS		Hβ EM		Hβ ABS	
	WIDTH	NO.	WIDTH	NO.	WIDTH	NO.	WIDTH	NO.
	Å		Å		Å		Å	
1912			1.80	2	5.39	7	1.85	5
1913	4.55	5	1.88	5	5.22	11	1.58	6
1914	3.81	3	1.90	3	5.13	8	0.96	2
1915	4.34	7	1.72	7	5.24	6	1.04	3
1916	4.26	6	1.92	2	4.88	6		
1918–19	3.94	2	1.83	2	5.06	10		
MEAN	4.26	23	1.82	21	5.16	48		

performance of the narrow hydrogen lines in the spectrum of κ Draconis, it seemed important to measure this line on as many plates as possible. The velocities, 23 in number, are found in the tenth column of Table 1. When these velocities are plotted against the phases in the third column of the table, they appear to be represented by a horizontal line about as well as by the velocity curve of the broad lines. Having decided against the connection of the K line with the broad lines, it remains to test their relation to the narrow hydrogen lines.

In Table 5 we have the mean velocities by years from the narrow hydrogen lines and from the K lines. It is evident that the K line also moves gradually toward the less refrangible end of the spectrum, aside from a set-back in 1916 from which it fully recovers. The differences, in the sixth column of the table, between the mean velocities from the hydrogen and calcium lines are remarkably accordant, if we overlook the difference for 1916 which depends on only two measures of the calcium line. The average difference, more than 10 km., is larger than we might have anticipated. However, it is not much larger than the average difference between the velocities from Hβ and Hγ; and it would be considerably smaller, had we made the velocities from the hydrogen lines homogeneous relative to the mean of the hydrogen lines instead of taking Hγ as the standard.

In the last column of Table 5 we have the broad line velocity residuals from the final curve assembled in yearly means. The lack of progression in these values shows that the velocity of the center of mass of the short period binary does not vary in company with the narrow hydrogen and calcium lines.

TABLE 5

MEAN VELOCITIES

YEAR	MEAN H		3933 (K)		DIFFERENCE	4471 AND 4861 EM.	
	NO. PLATES	VEL.	NO. PLATES	VEL.		NO. PLATES	O − C
		km.		km.	km.		km.
1912	12	−6.7				12	+1.9
1913	28	+1.7	4	−12	+14	25	−1.0
1914	8	+2.6	1	− 7	+10	7	−7.2
1915	18	+6.4	7	− 5	+11	16	+1.5
1916	10	−2.6	2	−26	+23	9	0.0
1918–19	20	+8.7	2	− 2	+11	17	+1.9

THE NARROW ABSORPTION LINES IN GENERAL

So far as they have been measured, the narrow absorption lines in the spectrum of κ Draconis differ from the broad absorption and emission lines in two respects: (1) They do not share the short period oscillation of the broad lines; (2) They undergo a gradual change in position which is not observed in the case of the broad lines.

An attempt to interpret these differences at present would be premature, since the nature of the variation of the narrow hydrogen lines is left undetermined by the Ann Arbor observations. It will be proper, however, to examine three possible interpretations and to mention their favorable features and limitations in the light of the present observations. Let us suppose:

1. The narrow absorption lines of hydrogen are reversals of the underlying emission. Mer-

rill, in *Lick Observatory Bulletin*, Volume 7, page 176, concurs with the majority of astronomers who have studied stellar spectra of this class in his conclusion that "complex self-reversal in the star's atmosphere is perhaps the best explanation we can offer at present for this perplexing phenomenon." Disappearance of the narrow Hβ is not out of accord with this supposition. Between Hγ which shows the overlying absorption strongly and Ha which perhaps fails to show it, this line may be unstable, disappearing and reappearing with changes at the proper level in the star's atmosphere which are too slight to affect noticeably the more stable Hγ.

The gradual shifting of the narrow hydrogen lines may be the result of changes in the complex line structure; this would serve to explain the second difference we have noted above between the narrow and broad lines. But, if the narrow lines are produced in the chromosphere of the star which gives the broad lines, the first difference remains without interpretation. Moreover, it is not at once apparent that the intimate connection of the calcium line with the narrow hydrogen absorption can be reconciled with our first assumption.

2. The narrow absorption lines are due to a medium either lying between us and the binary or else enveloping that system. Since Hartmann's announcement in the *Astrophysical Journal*, Volume 19, page 286, of the invariable K line among the oscillating lines in the spectrum of δ Orionis, many cases have been encountered in the spectra of early type binary stars where the K line differs in behavior from the others. The current explanation is the supposition with which this section begins. The feeble absorption of the medium can be noticeable, of course, only in the case of weak absorption within the star itself by the element or elements which compose the medium; or in case the effacing star lines are sufficiently displaced by the revolution of the star. This consideration may explain in part the preference of the peculiar K line for stars of types preceding the strong development of the K line and the failure up to the present time, so far as I know, to find "invariable hydrogen lines" associated with the calcium. The broad emission lines in the spectra of κ Draconis and similar stars afford a favorable background for the hydrogen lines of the supposed cloud. It is obvious that, if the star is single, there is no substantial difference between the first assumption and the latter part of the second one. But the cloud theory fails in the case of κ Draconis, unless we can account for the gradual shifting of the narrow calcium and hydrogen lines.

3. The narrow absorption lines are due to a third star in the system. This assumption may explain at least the two differences between the narrow and broad lines with which we started. If the narrow lines perform a regular oscillation, the yearly mean velocities in Table 5 suggest a period of something like four years and a velocity range of about 12 km. with maximum velocity of recession in 1915 and again in 1919. Unless the mass of the third star is much less than the combined masses of the close pair, we ought to find a corresponding gradual change in the velocities of the short period binary. While the first three values in the last column of Table 5 show a progression in the opposite direction to those in the third column, it will be noted that the mean of the residuals for 1915 or 1918-19, the years of maximum positive velocity for the narrow lines, is about the same as that for 1912, when the narrow lines yield minimum velocities. So far nothing is antagonistic to the supposition that κ Draconis is a triple system consisting of a short period binary whose brighter component is of type B5 with bright hydrogen lines, and a distant, *less massive* companion of Class A having a revolution period of several years.

But the disappearance of the narrow Hβ will require explanation. It may be that this is due to no change in the narrow line, but to a slight variation in the intensity of the underlying emission. Unfortunately I made no estimates of intensities of the emission during the measurement of the plates. An alternative view that varying intensity of the narrow Hβ may result from different degrees of superposition of two narrow absorption lines appears to have little foundation; for, of the two years, 1912 and 1916, when the narrow lines give minimum velocities, Hβ is most conspicuous in the first and does not appear in the second.

SUMMARY

The present paper is one of a series of studies of Class B stellar spectra having bright lines which Professor Curtiss has instituted at the Detroit Observatory. A number of interesting features are brought out in the study of the spectrograms of κ Draconis which accumulated at Ann Arbor between the years 1912 and 1919.

1. The broad absorption and emission lines are found to oscillate in a period of 8.986 days. The elements of the orbit are derived from measures of two of these lines.

2. The narrow hydrogen absorption lines which appear nearly central upon the broad emission do not share the short period oscillation. They are not stationary, however, but gradually change position. If their variation is periodic, the Ann Arbor velocities suggest a period of about four years and a velocity range of 12 km. a second. The broad lines appear to have no part in this gradual displacement.

3. The narrow Hβ absorption, which is frequently measured on the early plates, diminished in width during the interval 1912-15 and thereafter is not seen.

4. Special attention has been given to the K line which is feeble and indefinite. The behavior of this line is found to resemble that of the narrow hydrogen lines.

5. While the interpretation of the unlike performances of the broad and narrow lines is left open, certain limitations of three possible explanations are pointed out in the light of the Ann Arbor observations.

Columbia, Mo., September 17, 1920.

THE SPECTRUM AND ORBIT OF SIGMA CYGNI

By F. HENROTEAU

INTRODUCTION

The spectroscopic binary, σ Cygni, ($\alpha = 21^h\ 14^m$, $\delta = +39^\circ\ 2'$; magn., 4.5; spectrum, B8p) was discovered by Professor W. W. Campbell, from a plate taken in September, 1906, and was announced in 1910 in *Lick Observatory Bulletins*, Vol. 5, p. 176. Although the range of the star was supposed to be very small (not more than 7 km. according to Professor Campbell's prediction) the study of this star promised to be very interesting owing to the good definition of the spectral lines and certain physical peculiarities revealed by its spectrum. It was thought also that the determination of its orbit might serve as a test of what can be done in a case of this kind with an instrument of small dispersion like the single prism spectrograph of the Detroit Observatory.

HISTORICAL

The study of σ Cygni has never been attempted on an extensive scale before. Of short period binaries it has the smallest range of any investigated. The only star that can be compared with it in this respect is α Ursæ Minoris of which the range is about 6 km., whereas here the range is only 4 km. The previous measures of the radial velocity of σ Cygni, as given in *Lick Observatory Bulletins*, Vol. 5, are the following ones.

GR. M. T.	VELOCITY	OBSERVER	MEASURED BY
1902 Sept. 10.843	− 1.6 km.	Reese and Curtis	Lows
1903 July 7.989	− 11.7	Curtis	Lows
1904 Aug. 16.721	− 4.9	Moore	Lows
1906 Sept. 2.710	− 10.3	Campbell	Lows
1907 July 17.955	− 8.2	Albrecht	Lows
1908 Nov. 9.622	− 5.5	Wright	Merrill

These are apparently the only data published for this star.

OBSERVATIONS

Observations of σ Cygni were begun by the writer at the Detroit Observatory on June 12, 1916, and were continued until October of that year. During this interval more than 100 spectrograms, all on Seed 23 plates, were made with the one-prism spectrograph attached to the 37½-inch reflector. As a rule the exposures were of forty minutes' duration.

SPECTRUM

The spectrum of σ Cygni is of Class B8p. The series of hydrogen lines Hβ, Hγ, Hδ, Hϵ, Hζ, Hη, Hθ, are strong in this spectrum. Helium lines, silicon lines, and a good many metallic lines, most of them well-defined and bordered by emission, may be used successfully. The calcium lines H and K are sharp and are also situated in broad emission lines, a fact that will be considered in further discussion. The region used in the determination of the radial velocities extends from λ 3770 to λ 4862. The comparison spectrum is that of the titanium spark.

MEASUREMENT

All the spectrograms have been measured with one of the measuring engines of this Observatory. The screw error of these engines had been accurately determined by the writer and found so small that correction of the micrometer readings was unnecessary. About twenty comparison lines were used on each plate. All of the plates were measured direct and reversed, in order to eliminate personal equation as far as possible.

WAVE-LENGTHS

Twenty-five star lines were selected for use in the determination of the radial velocities. The wave-lengths were taken from published tables containing such quantities and are incorporated in Table 1. Wherever a line was used which could not be identified in some published table the wave-length was computed from the Hartmann formula,

$$\lambda = \lambda_0 + \frac{c}{R_0 - R},$$

to which a correction was applied, from a correction curve deduced by the writer from the comparison lines. The constants of this formula had been determined previously by the writer.

COMPARISON LINES AND DISPERSION CURVE

The dispersion of the single-prism spectrograph employed in this investigation having been changed since Mr. Mellor's study of its dispersion constants (see these *Publications*, Vol. I, p. 140), the micrometer readings for the principal titanium lines, the constants of the Hartmann formula, the values of $\frac{d\lambda}{dR}$, and a new dispersion curve had to be computed. Since these quantites will be needed in further studies, as they have been used in the course of the present one, it seems desirable to publish them here. They will be useful in the reduction of all plates made here since October 22, 1914.

For the purpose of redetermining these quantities six plates were selected for measurement from our observing list of stellar spectra. On account of the great number of lines studied, each plate was measured in two sections, the first from λ 3750 to λ 4331, the second from λ 4331 to λ 5000. Each plate was measured twice, direct and reversed, and throughout the reduction each half was treated separately. Six settings were made on each pair of lines, approaching always from the same direction with a speed as nearly constant as possible. Special care was taken in order that no change in illumination should occur during the measures. The mean of the measures made on the six plates gave for the principal titanium lines the micrometer readings in column two of the following table, reduced to zero and dispersion of Plate 3465. In column one the adopted laboratory wave-lengths and in column three the corresponding observed wave-lengths are given.

TABLE 1

DISPERSION TABLE OF TITANIUM LINES

LABORATORY	R	OBSERVED
3753.017	39.962	3753.986
3757.836	40.422	3757.877
3759.449	40.567	3759.429
3761.469	40.755	3761.438
3875.434	50.668	3875.471
3900.711	52.681	3900.705
3904.960	53.012	3904.930
3913.640	53.685	3913.580
3921.584	54.301	3921.581
3924.687	54.538	3924.677
3930.026	54.947	3930.053
3932.188	55.099	3932.056
3947.924	56.288	3947.897
3948.825	56.359	3948.855
3956.479	56.926	3956.524
3958.366	57.061	3958.364
3963.013	57.404	3963.045
3989.930	59.338	3989.909
3998.804	59 963	3998.774
4024.733	61.763	4024.794

TABLE 1

DISPERSION TABLE OF TITANIUM LINES
CONTINUED

LABORATORY	R	OBSERVED
4026.691	61.895	4026.733
4028.495	62.015	4028.498
4030.652	62.160	4030.637
4053.982	63.723	4053.994
4055.181	63.861	4055.180
4060.422	64.147	4060.437
4082.609	65.586	4082.635
4112.874	67.490	4112.826
4127.692	68.414	
4137.437	68.996	4137.391
4163.829	70.576	4163.841
4172.077	71.059	4172.071
4186.301	71.885	4186.311
4263.295	76.153	4263.307
4274.746	76.760	4274.768
4306.081	78.382	4306.005
4318.818	79.035	4318.853
4330.873	79.631	4330.720
4338.081	80.001	4338.121
4341.534	80.171	4341.443
4344.456	80.311	4344.366
4374.963	81.807	4375.025
4387.025	82.381	4387.035
4399.944	82.989	4399.908
4404.486	83.206	4404.543
4411.252	83.519	4411.269
4443.975	85.015	4443.966
4449.326	85.255	4449.295
4455.493	85.531	4455.465
4457.603	85.626	4457.594
4468.664	86.115	4468.626
4481.439	86.676	4481.410
4496.327	87.322	4496.308
4512.906	88.031	4512.890
4518.202	88.257	4518.227
4522.981	88.457	4522.969
4544.864	89.371	4544.896
4563.947	90.149	4563.993
4572.158	90.482	4572.216
4590.139	91.204	4590.147

TABLE 1

DISPERSION TABLE OF TITANIUM LINES
CONTINUED

LABORATORY	R	OBSERVED
4617.440	92.276	4617.433
4623.268	92.504	4623.316
4656.622	93.774	4656.629
4682.084	94.721	4682.070
4691.504	95.068	4691.530
4698.940	95.336	4698.886
4742.965	96.909	4742.941
4841.038	100.223	4841.053
4856.187	100.713	4856.213
4900.089	102.100	4900.077
4981.916	104.571	4981.946
4991.248	104.841	4991.200
4999.683	105.088	4999.720

Five lines, selected on account of their sharpness and proper spacing on the negative, were made use of in computing two sets of constants by the Hartmann Interpolation formula,

$$\lambda = \lambda_0 + \frac{c}{R_0 - R},$$

where λ, c, and R_0 are constants depending upon the measures, λ representing the assumed wave-lengths and R the corresponding screw readings. The values of the known quantities for three lines occurring on the first half of the plate were

λ	R
3904.960	53.012
4024.733	61.763
4330.873	79.631

and those for the second half

λ	R
4330.873	79.631
4455.493	85.531
4841.038	100.223

Substituting these values of each set independently in the above equation and solving, we obtained

$$\lambda_0 = 2213.640, \quad R_0 = 185.336, \quad c = 223802.23,$$

and

$$\lambda_0 = 2226.157, \quad R_0 = 185.177, \quad c = 222144.35.$$

The wave-lengths corresponding to the observed screw readings were then computed. The residuals obtained by subtracting the computed wave-lengths for the different screw readings corresponding to the titanium lines, from Rowland's standard wave-lengths assumed for these lines furnished the dispersion curve of the spectrograph. This curve gives us the correction to be applied to a wave-length deduced from any screw reading by the Hartmann formula to obtain the corresponding true wave-length.

Table 2 computed by the writer gives for each whole turn of the screw the corresponding values of

$$\frac{d\lambda}{dR}, \ \lambda, \ \frac{dv}{d\lambda}, \text{ and } \frac{dv}{dR}.$$

TABLE 2

SPECTROGRAPH CONSTANTS

R	$\frac{d\lambda}{dR}$	λ	$\frac{dv}{d\lambda}$	$\frac{dv}{dR}$
39	10.45	3743	80.11	837
40	10.59	3754	79.88	846
41	10.74	3765	79.64	855
42	10.89	3775	79.43	865
43	11.05	3786	79.20	875
44	11.20	3797	78.97	884
45	11.36	3809	78.72	894
46	11.53	3820	78.50	905
47	11.68	3832	78.25	914
48	11.86	3844	78.01	925
49	12.04	3855	77.78	936
50	12.22	3868	77.52	947
51	12.40	3880	77.28	958
52	12.59	3893	77.03	970
53	12.78	3905	76.79	981
54	12.97	3918	76.53	993
55	13.17	3931	76.28	1005
56	13.38	3944	76.03	1017
57	13.59	3958	75.76	1030
58	13.81	3972	75.50	1043

TABLE 2

SPECTROGRAPH CONSTANTS

CONTINUED

R	$\frac{d\lambda}{dR}$	λ	$\frac{dv}{d\lambda}$	$\frac{dv}{dR}$
59	14.02	3985	75.25	1055
60	14.24	4000	74.97	1068
61	14.48	4014	74.70	1082
62	14.71	4029	74.43	1095
63	14.95	4043	74.17	1109
64	15.20	4058	73.89	1123
65	15.45	4074	73.60	1137
66	15.71	4089	73.33	1152
67	15.98	4105	73.05	1167
68	16.25	4121	72.76	1182
69	16.53	4137	72.48	1198
70	16.83	4154	72.19	1215
71	17.12	4171	71.89	1231
72	17.42	4189	71.58	1247
73	17.73	4206	71.29	1264
74	18.05	4224	70.99	1281
75	18.38	4242	70.69	1299
76	18.72	4261	70.37	1317
77	19.06	4280	70.06	1335
78	19.42	4299	69.75	1355
79	19.79	4319	69.43	1374
80	20.17	4338	69.12	1394
80	20.08	4338	69.12	1388
81	20.47	4358	68.81	1409
82	20.87	4379	68.48	1429
83	21.28	4400	68.15	1450
84	21.70	4422	67.81	1471
85	22.13	4443	67.49	1494
86	22.58	4466	67.14	1516
87	23.05	4489	66.80	1540
88	23.52	4512	66.46	1563
89	24.01	4536	66.11	1587
90	24.52	4560	65.76	1612
91	25.04	4585	65.40	1638
92	25.58	4610	65.05	1664
93	26.14	4636	64.68	1691
94	26.72	4662	64.32	1719
95	27.32	4689	63.95	1747
96	27.93	4717	63.57	1776
97	28.57	4745	63.20	1806
98	29.23	4774	62.81	1836
99	29.91	4804	62.42	1867

TABLE 2

SPECTROGRAPH CONSTANTS

CONTINUED

R	$\frac{d\lambda}{dR}$	λ	$\frac{dv}{d\lambda}$	$\frac{dv}{dR}$
100	30.62	4834	62.03	1899
101	31.35	4865	61.64	1932
102	32.10	4897	61.23	1965
103	32.90	4929	60.84	2002
104	33.71	4962	60.43	2037
105	34.56	4997	60.01	2074

RADIAL VELOCITIES

The velocities were determined from the measures in the usual manner. Corrections were applied for the orbital velocity of the earth, for the earth's rotation, for the curvature of the lines, and for the small increments in Column 2 of Table 3, which were applied to the wave-lengths of the several star lines to make them homogeneous.

The correction for making the lines homogeneous was made in the following manner. Residuals were found from a comparison of the velocity as given by the line and the velocity as given by the plate. A correction was then applied to

TABLE 3

WAVE-LENGTHS OF LINES MEASURED

WAVE-LENGTHS		$\Delta\lambda$	WT.	MICROMETER READING R	ELEMENT
Hι	3770.780			41.622	Hydrogen
Hθ	3798.050			44.093	Hydrogen
	3856.200	− 0.006	16	49.089	Silicon
	3862.800	− 0.051	16	49.634	Silicon
Hζ	3889.200	0.000	14	51.771	Hydrogen
K	3933.833	− 0.034	29	55.233	Calcium
H	3968.625	− 0.015	19	57.811	Calcium
Hϵ	3970.177	+ 0.133	17	57.923	Hydrogen
	4009.420	+ 0.024	2	60.706	Helium
	4026.359	+ 0.070	9	61.870	Helium
	4067.139	+ 0.107	2	64.585	Iron
Hδ	4101.920	− 0.003	26	66.809	Hydrogen
	4128.204	+ 0.088	20	68.437	Silicon
	4131.040	+ 0.018	20	68.611	Silicon
	4144.038	− 0.087	1	69.397	Iron
	4169.183			70.890	Helium
	4179.020	− 0.071	9	71.464	Iron
	4233.328	− 0.024	19	74.530	Iron
	4303.420	− 0.083	7	78.250	Iron
Hγ	4340.634	+ 0.027	29	80.125	Hydrogen
	4352.083	− 0.115	10	80.692	Magnesium
	4471.676	+ 0.027	9	86.250	Helium
	4481.397	− 0.015	21	86.675	Magnesium
	4549.642	− 0.046	8	89.567	Iron
Hβ	4861.527	− 0.062	16	100.884	Hydrogen

each line which would reduce to zero the algebraic sum of the residuals of that line for all of the plates on which it was measured.

For each radial velocity, weights were determined which were taken into account in the determination of the velocity curve.

Table 4 gives the velocity obtained from each spectrogram. The velocity obtained from the line $H\epsilon$ is given separately, since the variation of that velocity is different from the variation of the star's velocity.

TABLE 4

NO. OF PLATE	DATE G. M. T. 1916	VELOCITY	VELOCITY GIVEN BY $H\epsilon$
	h m	km.	km.
3520	June 12, 17 50	− 10.20	+ 7.16
3524	21, 16 40	− 6.84	+ 6.45
3525	22, 16 0	− 7.40	+ 13.35
3526	22, 17 12	− 8.52	+ 2.31
3527	22, 17 59	− 5.18	+ 3.27
3529	25, 17 25	− 5.60	+ 8.91
3530	25, 18 14	− 2.91	+ 1.86
3534	30, 16 24	− 3.14	+ 13.24
3535	30, 17 6	− 3.06	+ 3.21
3538	July 1, 16 20	− 3.51	+ 9.08
3539	1, 17 25	− 7.38	+ 7.03
3540	1, 18 7	− 7.24	+ 4.98
3542	2, 16 7	− 4.34	+ 7.80
3543	2, 17 30	− 6.27	+ 3.85
3544	3, 15 32	− 7.47	+ 5.78
3545	3, 17 2	− 6.56	+ 5.72
3547	4, 15 57	− 4.11	+ 11.60
3550	5, 16 22	− 5.77	+ 10.40
3551	5, 17 34	+ 0.15	+ 11.34
3552	5, 18 16	− 4.18	+ 10.29
3558	7, 18 7	− 2.25	+ 10.94
3561	9, 18 30	− 3.63	+ 6.52
3565	11, 17 30	− 7.08	+ 3.81
3566	15, 16 15	− 7.69	+ 15.50
3567	15, 17 10	− 3.52	+ 10.37
3571	18, 16 50	− 3.09	+ 8.72
3572	18, 17 32	+ 0.50	+ 9.67
3573	18, 18 13	− 1.59	+ 4.63
3578	21, 18 20	− 1.59	+ 7.91
3579	21, 19 0	− 2.32	+ 17.89
3584	23, 17 56	− 0.32	+ 9.44
3585	23, 18 36	− 1.26	+ 15.39
3587	24, 18 35	− 8.66	+ 3.13
3589	25, 18 15	− 7.18	+ 4.93
3590	25, 18 55	− 4.50	+ 10.87

TABLE 4 — CONTINUED

NO. OF PLATE	DATE G. M. T. 1916	VELOCITY	VELOCITY GIVEN BY $H\epsilon$
	h m	km.	km.
3592	July 26, 18 35	− 7.50	+ 12.61
3599	29, 19 35	− 5.75	+ 9.57
3600	31, 14 33	+ 6.56	+ 3.61
3601	31, 15 44	− 2.61	+ 9.54
3602	Aug. 1, 14 8	− 1.91	+ 13.36
3603	1, 14 48	+ 2.29	+ 15.33
3606	2, 15 5	− 3.40	+ 1.14
3607	2, 15 45	− 5.15	
3611	5, 20 40	− 5.71	+ 9.79
3614	13, 13 47	− 3.35	+ 9 95
3615	13, 14 27	− 1.73	+ 1.92
3616	14, 15 45	− 3.63	+ 9.52
3617	14, 16 46	− 5.56	− 4.56
3618	14, 17 26	− 3.65	+ 5 18
3620	16, 17 0	− 4.30	+ 2.81
3621	16, 17 57	− 6.23	+ 6.64
3623	18, 15 29	+ 2.64	+ 6.47
3624	18, 16 10	− 0.70	+ 6.43
3625	18, 16 50	+ 1.80	− 0.61
3634	20, 15 45	− 4.22	+ 4.83
3635	20, 16 25	− 3.07	+ 5.81
3636	20, 17 15	− 6.10	− 0.26
3637	20, 17 57	− 3.09	+ 5.29
3638	21, 15 45	− 1.69	+ 7.53
3639	21, 16 25	− 2.86	+ 6.49
3641	21, 18 37	− 0.58	+ 0.33
3642	23, 13 31	− 0.44	+ 6.98
3643	23, 14 11	− 0.58	+ 13.97
3644	23, 14 51	− 2.43	+ 11.95
3645	23, 16 5	− 1.32	
3646	23, 16 45	− 1.69	+ 2.85
3647	23, 17 25	− 1.23	+ 10.80
3649	25, 14 35	+ 3.26	
3650	25, 15 15	+ 0.07	+ 2.32
3654	27, 14 45	− 2.76	+ 19.70
3655	27, 17 4	− 0.46	+ 3.57
3677	Sept. 8, 20 20	− 6.29	+ 11.51
3683	17, 13 58	− 5.55	+ 6.17
3684	17, 16 30	− 4.76	+ 2.00
3688	18, 14 47	− 3.43	+ 5.72

TABLE 4 — CONTINUED

NO. OF PLATE	DATE G. M. T. 1916	VELOCITY	VELOCITY GIVEN BY Hε
	h m	km.	km.
3689	Sept. 18, 15 29	− 4.34	+ 1.77
3693	21, 18 0	− 7.61	+ 4.67
3697	23, 16 0	− 6.18	− 0.78
3698	23, 16 42	− 3.73	+ 2.17
3699	24, 15 2	− 4.20	+ 3.99
3700	24, 15 44	− 3.68	+ 10.95
3703	25, 15 30	− 3.30	− 3.33
3704	25, 16 15	− 3.60	− 4.39
3708	29, 17 30	− 7.22	
3709	29, 18 10	− 9.03	+ 6.29
3712	30, 15 20	− 6.45	+ 2.23
3713	30, 16 0	− 6.39	+ 7.19
3716	Oct. 1, 14 45	− 3.19	+ 8.99
3717	1, 15 25	− 2.67	+ 10.94
3722	2, 15 30	− 4.34	+ 4.66
3723	2, 16 10	− 6.28	+ 13.62
3732	6, 14 0	− 6.32	− 2.32
3733	6, 14 40	− 5.29	+ 0.62
3736	9, 13 40	− 7.29	+ 3.91
3737	9, 14 25	− 3.90	+ 4.85
3745	13, 14 30	− 1.33	+ 3.84
3746	13, 15 10	− 2.83	+ 1.79
3750	16, 15 44	− 1.06	
3751	16, 16 40	− 1.36	+ 2.02
3759	22, 14 30	− 1.98	+ 9.81

NORMAL PLACES

Since the period of the orbit is very nearly eleven days and since the intervals of time over which observations of any nights extended were relatively small, the observed radial velocities were combined into normal places for each date. Forty-nine normal places were obtained in this way. The weight for each plate was determined on the basis of the sum of the weights of the plates combined to make the normal place. The largest of these sums was taken as unity and the rest reduced to this basis.

Table 5 gives the velocities obtained from these normal places, as well as their weights. The dates are reckoned from 1916 June $12^{d}.00$, G. M. T. The phases are reckoned from the epoch, 1916, July $15^{d}.00$, G. M. T., and are computed with the final period, 11.043 days. The two last columns give the residuals obtained after the last least squares solution had been computed; the first one gives the residuals obtained from direct substitution in the equations of condition, while the second one gives those obtained from the final ephemeris.

TABLE 5

NORMAL PLACES

DATE	PHASE	VELOCITY	WEIGHT	RESIDUALS	
				O — C	O — C
Days	Days	km.		km.	km.
0.74	0.87	− 10.20	0.198	− 5.34	− 5.28
9.70	9.83	− 6.84	0.370	− 0.69	− 0.77
10.71	10.84	− 7.67	0.654	− 1.90	− 1.89
13.75	2.84	− 3.94	0.321	− 0.26	− 0.27
18.70	7.79	− 3.10	0.407	− 0.83	− 0.71
19.72	8.81	− 6.42	0.593	− 2.42	− 2.51
20.72	9.81	− 5.82	0.580	+ 0.32	+ 0.24
21.68	10.77	− 7.06	0.358	− 1.24	− 1.23
22.66	0.70	− 4.11	0.296	+ 0.93	+ 0.94
23.72	1.76	− 4.84	0.358	− 0.55	− 0.55
25.76	3.80	− 2.25	0.519	+ 0.96	+ 0.94
27.77	5.81	− 3.63	0.148	− 1.21	− 1.21
29.73	7.77	− 7.08	0.074	− 4.80	− 4.70
33.70	0.70	− 4.63	0.370	+ 0.42	+ 0.42
36.73	3.73	− 1.75	0.778	+ 1.49	+ 1.48
39.78	6.78	− 1.77	0.407	+ 0.42	+ 0.44
41.77	8.77	− 0.93	0.321	+ 2.96	+ 2.88
42.78	9.78	− 8.66	0.185	− 2.57	− 2.63
43.78	10.78	− 5.84	0.296	− 0.03	− 0.02
44.78	0.74	− 7.50	0.123	− 2.48	− 2.48
47.82	3.78	− 5.75	0.407	− 2.53	− 2.55
49.63	5.59	− 1.08	0.222	+ 1.42	+ 1.41
50.61	6.57	+ 0.76	0.272	+ 2.98	+ 3.00
51.65	7.61	− 4.49	0.198	− 2.25	− 2.19
54.86	10.82	− 5.71	0.136	+ 0.01	+ 0.01
62.59	7.50	− 2.81	0.444	− 0.59	− 0.55
63.69	8.60	− 4.09	0.728	− 0.63	− 0.67
65.73	10.64	− 5.11	0.469	+ 0.81	+ 0.82
67.58	1.45	+ 1.25			
69.70	3.57	− 4.06	0.617	− 0.75	− 0.76
70.70	4.57	− 1.51	0.494	+ 1.37	+ 1.35
72.65	6.52	− 1.26	1.000	+ 0.98	+ 0.99
74.63	8.50	+ 1.41	0.383	+ 4.65	+ 4.63
76.67	10.54	− 1.35	0.222	+ 4.63	+ 4.64
88.85	0.63	− 6.29	0.123	− 1.20	− 1.19
97.64	9.42	− 5.23	0.432	+ 0.33	+ 0.26
98.64	10.42	− 4.03	0.506	+ 2.03	+ 2.03
101.75	2.49	− 7.61	0.025	− 3.75	+ 3.75
103.69	4.43	− 4.92	0.407	− 2.00	− 2.00
104.67	5.41	− 4.05	0.531	− 1.50	− 1.50

TABLE 5

NORMAL PLACES — CONTINUED

DATE	PHASE	VELOCITY	WEIGHT	RESIDUALS	
				O — C	O — C
Days	Days	km.		km.	km.
105.67	6.41	− 3.45	0.395	− 1.18	− 1.18
109.75	10.49	− 7.70	0.185	− 1.68	− 1.68
110.66	0.36	− 6.41	0.420	− 1.10	− 1.09
111.63	1.33	− 2.88	0.432	+ 1.70	+ 1.70
112.66	2.36	− 5.13	0.272	− 1.21	− 1.20
116.60	6.30	− 5.78	0.284	− 3.49	− 3.49
119.59	9.29	− 6.16	0.333	− 0.91	− 0.97
123.62	2.28	− 1.89	0.630	+ 2.08	+ 2.09
126.68	5.34	− 1.25	0.259	+ 1.32	+ 1.32
132.60	0.22	− 1.98	0.185	+ 3.46	+ 3.46

PRELIMINARY ELEMENTS

The velocities were first plotted on a continuous piece of paper and from the distribution of the points the period was estimated to be between nine and twelve days. Several periods were assumed and the points plotted accordingly. For an assumed period of 11.00 days, the points, when combined into new normal places, followed a well determined velocity curve. After determining the approximate period, a first preliminary orbit was found graphically by the method of Lehmann-Filhés (*Astronomische Nachrichten*, Vol. 136, p.17, 1894), and this was afterward corrected by the method of least squares.

LEAST SQUARES SOLUTIONS

Owing to the small range in radial velocity and the large corrections required by some of the elements, particularly the eccentricity, the problem of correcting the preliminary orbit was somewhat complicated. Five least squares solutions were made before satisfactory elements were obtained. The method used in these solutions was essentially that outlined by Dr. Schlesinger in Volume I of the *Allegheny Publications*, but the corrections to the elements resulting from the first solution were so great that it was not reasonable to expect convergence. Accordingly arbitrary variations were introduced and it was only after the third least squares solution that convergence was obtained.

The last preliminary elements, obtained after the fourth least squares solution, are

$$\begin{aligned} V &= -3\ .74 \text{ km.} \\ P &= 11\ .070 \text{ days} \\ e &= 0\ .36 \\ K &= 1\ .99 \text{ km.} \\ \omega &= 115^\circ\ 52' \\ T &= 8^d.96 \end{aligned}$$

in which T is measured from 1916, July 15.00, Gr. M. T.

The normal equations for the correction of the fourth preliminary elements are as follows:

NORMAL EQUATIONS

$$\begin{aligned} 18.367\Gamma + 1.025\kappa - 5.197\pi - 3.378\epsilon - 0.301\tau - 0.121m + 1.01 &= 0 \\ 9.034\kappa - 0.377\pi + 1.408\epsilon + 0.065\tau - 0.174m + 0.51 &= 0 \\ 9.336\pi + 0.861\epsilon + 4.358\tau + 0.751m - 2.44 &= 0 \\ 2.288\epsilon - 0.100\tau + 0.073m + 0.29 &= 0 \\ 2.858\tau + 0.455m - 1.45 &= 0 \\ 0.390m - 0.03 &= 0 \end{aligned}$$

From these equations the values of the unknown quantities were found to be

$$m = -0.044$$
$$\tau = +0.838$$
$$\epsilon = -0.223$$
$$\pi = -0.144$$
$$\kappa = -0.029$$
$$\Gamma = -0.153$$

The corrections to the elements are as follows:

$$\Delta\kappa = -0.01 \text{ km.}$$
$$\Delta\omega = +3^\circ.24$$
$$\Delta e = +0.04$$
$$\Delta\tau = +0.31 \text{ days}$$
$$\Delta\mu = +0^\circ.08$$
$$\Delta\gamma = -0.06 \text{ km.}$$

By adding these corrections to the preliminary elements, we obtain the following final elements, in which 1916, July 15.00, Gr. M. T. is taken as the epoch.

FINAL ELEMENTS

$$V = -3.80 \text{ km.}$$
$$P = 11.043 \pm 0.042 \text{ days}$$
$$e = 0.40 \pm 0.08$$
$$K = 1.98 \pm 0.186 \text{ km.}$$
$$\omega = 119^\circ\ 6' \pm 14^\circ\ 46'$$
$$T = 9.27 \pm 0.34 \text{ days}$$
$$a \sin i = 275{,}700 \text{ km.}$$
$$m_1^3 \sin^3 i\ (m + m_1)^{-2} = 0.000{,}007\ \odot$$

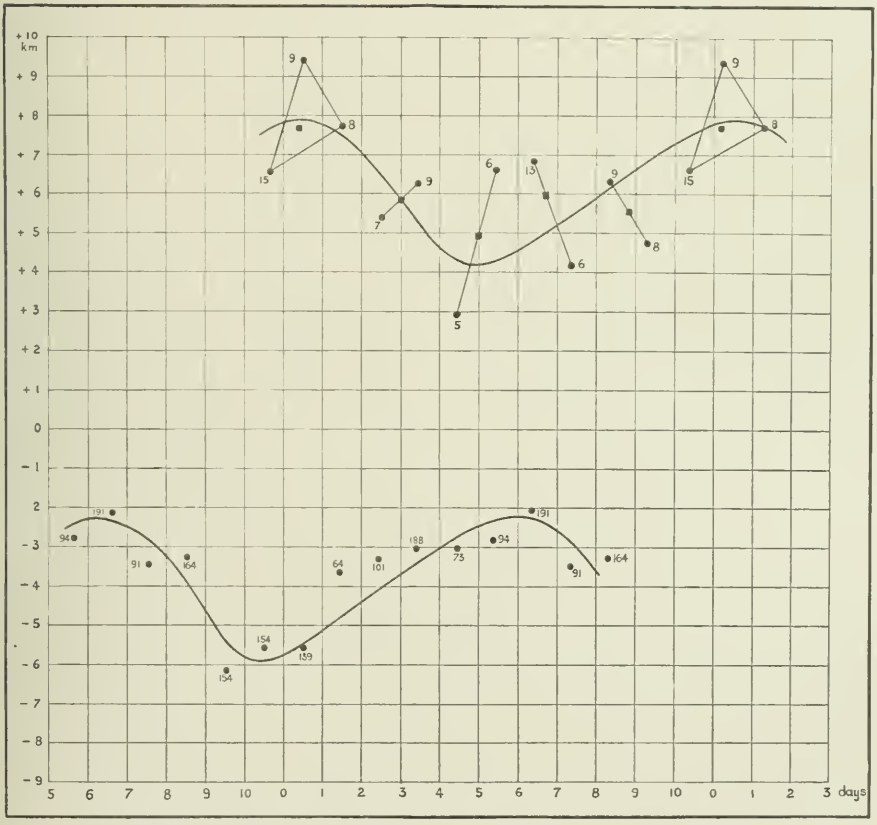


FIG. III. VELOCITY CURVES OF SIGMA CYGNI

A new ephemeris was now computed on the basis of the corrected elements and the residuals formed. These residuals were compared with the corrected residuals deduced from the ephemeris given by the uncorrected elements. These two sets of residuals are given in the two last columns of Table 5. The resulting differences show that a further least squares solution is unnecessary.

The curve corresponding to the final elements is shown in the lower diagram of Figure III. The velocities combined into eleven normal places, each including observations ranging in phase over one day, are compared with the curve in this diagram. The numbers near each plotted point express the relative weights of the normal places.

THE PERIOD

A slight correction to be applied to the period, $P = 11.043$ days, is indicated by comparison with the previous observations given by Professor Campbell in the *Lick Observatory Bulletins*. The new period computed in this manner is 11.055 days. This is probably the best period obainable from the available data. However the range of the velocity curve is so small that more observations would be needed to establish beyond question former epochs for the determination of the period. This corrected period is hardly strong enough to justify a new least squares solution nor would such a solution lead to important changes in the final elements.

The Lick Observatory radial velocities plotted on the basis of a period of 11.055 days are compatible with a velocity curve in reasonably close agreement in form with that derived by the writer, but with a velocity range perhaps a kilometer greater and a center of mass velocity about three kilometers greater negatively. Such small differences are not to be regarded as real changes in the orbital elements in view of the limited number of old velocities and the probability of systematic differences in the velocities.

VELOCITIES FROM Hε

It is evident from Table 4 that the line Hε, which is very near H of calcium (λ of H = 3968.625 and λ of Hε 3970.177), gives a velocity different from that derived from the other lines of the star. To determine whether the velocity variations derived from Hε were different from those obtained from the other lines the results for this line were isolated and reduced independently. Normal places were formed for them using the period derived from the studies of the other lines and the results were plotted in Figure III, where they fall in the upper part of the diagram. The normal places including phases ranging over a day each are plotted as small circles; and these are combined into five final means represented by black squares. As a whole the Hε velocities appear to be shifted about ten kilometers in the positive direction. They appear also to vary and perhaps to satisfy a curve similar in form to that derived from the normal lines but displaced along the time axis about a half period. In Figure III the upper curve is drawn on this hypothesis and apparently as drawn affords it some support.

Assuming provisionally that the Hε curve is displaced about a half-period in time and about ten kilometers positively in velocity with reference to the normal curve and recognizing also that emission associated with the H line of calcium extends at least partly over the Hε line, I have developed a theory to account for such a displacement on the ground that it is caused by relative retardation and a specific difference in path for the Hε light due to anomalous dispersion of calcium vapor in a "calcium cloud" between us and the star. This calcium cloud is assumed to emit bright line radiation visible as bright fringes at the edges of the H and K lines in the spectrum of σ Cygni. If such a cloud is present between us and that star it might be possible that such emission lines could be photographed by long exposures in this immediate neighborhood. But my efforts to do this have not met with success. Furthermore the assumed displacement of the velocity curve as a whole is not very well substantiated. At least until better evidence is available the publication of my theory may wisely be deferred. Photographs by Barnard showing "dark nebulæ" in this region are interesting in this connection.

It may be pointed out that the presence of emission fringes noted above on the edges of the

lines of other metals than calcium in the spectrum of σ Cygni would indicate that they too might be supposed to be present as emitting vapors in the cloud which my theory calls for. Iron, magnesium, and silicon would be included. Many would feel that evidence stronger than we have at present would be needed to inspire confidence in the existence of a cloud of this nature. Professor Curtiss suggests that the displacement of the Hϵ line toward the red is due to the emission which accompanied the neighboring H line of calcium and which covers and alters the apparent position of the violet edge of the Hϵ line producing an apparent displacement of this violet edge and therefore of the whole line toward the red. He points out that the hydrogen lines in this region of the spectrum of σ Cygni have diffuse edges and that therefore marked emission overlapping one of these edges would affect greatly the apparent position of the line. My observations are not strong enough to establish the character of the velocity variations of the Hϵ line. Professor Curtiss suggests that the variations observed, so far as they are real, are due to a combination of the variation determined for the normal lines with certain changes in the position of this Hϵ line due to variation in the calcium emission which overlaps its edge of shorter wave-length. Undoubtedly further discussion of the anomalies here observed would not be profitable until additional observations have established the nature of the Hϵ velocity curve. My observations of the absorption lines, Hδ, H and K, have each been segregated and reduced independently and have been found to satisfy the velocity curve deduced from the other normal lines. The Hϵ line is the only feature of this spectrum whose behavior is known to be abnormal.

SUMMARY

The foregoing paper is devoted more particularly to a discussion of the orbit of the spectroscopic binary, σ Cygni, a star with a smaller range in velocity than that of any binary of short period whose orbit has been derived.

The spectrum of this star is of Class B8p. Twenty-two well defined lines in its spectrum were used for velocity determinations. Lines of calcium, iron, magnesium, silicon and possibly others were found to have bright borders.

My standard tables and curves for the reduction of spectrograms made with the apparatus used were derived and are given above for future use.

Definitive elements of the orbit of σ Cygni were determined from one hundred velocities. The velocity range of this star is only 3.96 km.; the eccentricity, 0.40. The final period determined by a comparison of the writer's velocities with earlier observers at Lick Observatory is 11.055 days. The mass function is only 0.000,007 $\odot$; and the value of $a \sin i$, 275,700 km. The inclination of the orbit to the tangent plane is probably very small.

The Lick Observatory radial velocities agree reasonably well with my curve except for a difference of about three kilometers in the center of mass velocity due perhaps to systematic differences in velocity results.

Emission on the red edge of the H line of calcium overlaps the violet edge of the close Hϵ line.

Velocities derived from the Hϵ line are not in agreement with those derived from the other lines in this spectrum. If my two velocity curves, the one derived from the Hϵ line and the other from the remaining lines, are drawn relatively to the same axes of coordinates, the Hϵ curve resembles roughly the star curve in form but is shifted about a half period, or 5.5 days, along the time axis and displaced about ten kilometers upward along the velocity axis.

To account for the abnormal behavior of the Hϵ line the writer suggests an anomalous dispersion phenomenon combined with a difference of path in enormous clouds composed in part at least of calcium and situated between us and this star. Photographs by Barnard showing dark nebulæ in this region are interesting in this connection. The emission fringes on the edges of the H line of calcium overlapping the violet edge of the Hϵ line are assumed by me to be due to radiation from these calcium clouds. Emission borders near other lines in the spectrum of σ Cygni would suggest the presence of other incandescent metallic vapors in the supposed cloud in space.

But the form of the Hε curve is not well substantiated and no emission has been observed in the neighborhood of σ Cygni. Professor Curtiss suggests that the large displacement of the Hε line toward the red is due to the emission of calcium on the violet edge of this line and that the observed variations in the position of this line, in so far as they are real, are due to a combination of the variation due to orbital motion with small displacements due to slight variations in the intensity of the overlapping calcium emission.

It is with pleasure that I acknowledge my indebtedness to Professor Curtiss for his valuable advice and supervision in the present study. I wish also to express my gratitude to Professor W. J. Hussey and to Mr. R. P. Lamont of Chicago for the opportunity they have afforded me of pursuing astronomical research at the Observatory of the University of Michigan.

Ann Arbor, Michigan, 1917.

RADIAL VELOCITIES OF THE ANTAPEX GROUP OF STARS

By F. HENROTEAU

In an article published in the *Astronomical Journal*, Volume 27, page 83, 1912, Professor Benjamin Boss described his study of the systematic motions of the stars arranged according to spectral type. He had found previously (*Astronomical Journal*, Vol. 26, p. 163, 1910) that on the whole the peculiar motions of the Class B stars are at random in space, a result which Professor Campbell derived independently from a study of the radial velocities of these stars. (*Lick Observatory Bulletin*, No. 195.)

A preferential motion does exist, however, for later type stars, and it was thought probable that this motion was present in the stars of Class A since this class of stars follows Class B. Professor Boss undertook the study of Class A and late Class B stars in order to find if such preferential motion really existed. He succeeded in classifying these different stars in four groups of which one of them, the antapex group, seems to have a preferential motion towards the antapex of solar motion, the adopted convergent being $\alpha = 107°$, $\delta = -40°$ for 1875.0.

The different groups into which Professor Boss divides his stars are not, however, streams of stars in so true a sense as in the case of the Taurus group. On the basis of radial velocities for six stars of the antapex group, he suggests (*Astronomical Journal*, Vol. 28, p. 174, 1914) that, in the case of this group, the stars are practically at rest with reference to the stars from which the constants of the solar motion have been derived, or that their real velocity is zero relatively to such stars. His velocity for the group is +21 kilometers per second referred to the sun.

Further measurement of the radial velocities of the different stars of the antapex group was deemed important and values for all of the twelve stars of this group situated in the northern hemisphere have been determined by the writer and are discussed in the present paper. Of the twelve stars 124 spectrograms were taken with an average exposure of sixty minutes, were measured and reduced in the ordinary way, and were referred to the sun. The weighted mean of the several velocities of each star was taken as its radial velocity except in one case where the star was found to be a spectroscopic binary. In that case the center of mass radial velocity has been given.

In weighting the various lines measured for velocity determination some uncertainty was felt. Thus it was very hard to determine the relative weights of a very broad and diffuse line such as the hydrogen lines and a narrow and ill-defined line. It is more probable that the personal equation in the measurement of the former was greater than for the latter; the weights attributed to both kinds of lines were, however, always given as unity, and this has tended to make the scale of weights for the different stars nonhomogeneous, although giving an idea of the relative accuracy of the results, fairly reliable in any set of plates of a given star. However, too much importance ought not to be attached to the weights.

The probable errors of the mean velocities of each star are given with the data below. These probable errors, r and r_1, have been computed in two different ways: r, by taking the residuals for each plate from the mean velocity of all the plates; r_1, by taking the residuals for each line from the mean velocity for each plate. It is clear that if the second one is very much smaller than the first the star is probably a spectroscopic binary. On the other hand if the first is much smaller than the second it is an indication of the uncertainty of the results obtained, owing to the poor definition of the lines measured; but this happens only in one case.

ANN ARBOR OBSERVATIONS

The observational results for each star are given in the followiug tables, together with some explanatory remarks. In each table the different

columns give the number of the plate, the date, the Greenwich mean time of observation, the radial velocity, and the weight given to each plate. The positions of the stars are for the epoch 1900.0.

α PEGASI (P. G. C. 5944)

R.A. 22h 50m.8; Decl. +14° 40′

PLATE	DATE	GR. M. T.	VELOCITY	WEIGHT
3685	1916 Sept. 17	17h 30m	− 5.85 km.	12
3686		17 37	+ 3.79	13

Mean = −0.84 km.

Class, A. Magnitude, 2.6. Only two plates of this star were secured by the writer, because the radial velocity of α Pegasi had already been obtained at this Observatory from twenty plates by Mr. Mellor. His average velocity is −3.4 ± 0.8 km. No correction for Mr. Mellor's systematic personal equation has been applied. Lee has announced that α Pegasi is a binary with duplex lines. Our velocities, which are in good agreement for the several plates, are based upon the blended lines of the two components. The computed radial velocity based upon a group velocity of +21 kilometers relative to the sun is −11.7 km. The spectrum of α Pegasi has strong H and K absorption lines with emission on both sides of the K line.

κ PISCIUM (P. G. C. 6031)

R.A. 23h 21m.8; Decl. +0° 42′

PLATE	DATE	GR. M. T.	VELOCITY	WEIGHT
3724	1916 Oct. 2	17h 30m	+ 2.49 km.	9
3738	Oct. 9	16 20	− 6.94	8
3770	Oct. 30	13 52	− 0.74	12
3771	Oct. 30	14 38	+ 2.22	8
3788	Nov. 10	13 58	− 7.73	11
3789	Nov. 10	14 43	− 2.18	10
3813	Dec. 1	14 3	− 11.35	4
3814	Dec. 1	14 48	− 7.66	8
3821	Dec. 17	15 0	− 4.53	9
3827	Dec. 23	14 38	− 0.16	7

Mean = −3.26 km., r = ±0.9 km., r_1 = ±0.9 km.

Class, A2. Magnitude, 5.0 In No. 669 of the *Astronomical Journal*, Professor Boss mentions the observed radial velocity of this star as being −3.7 km., which is very near the value here obtained. The computed radial velocity based upon group velocity is −7.4 km.

BRADLEY 132 (P. G. C. 249)

R.A. 0h 2m.6; Decl. + 20° 12′

PLATE	DATE	GR. M. T.	VELOCITY	WEIGHT
3687	1916 Sept. 17	18h 33m	− 4.17 km.	2
3742	Nov. 5	16 25	+ 34.03	4
3783	Nov. 5	17 5	+ 14.04	6
3784	Nov. 5	18 10	+ 10.78	3
3792	Nov. 10	17 40	− 14.21	2
3793	Nov. 10	18 20	− 14.60	3
3802	Nov. 17	18 50	− 29.06	2
3815	Dec. 1	16 15	− 11.44	3
3816	Dec. 1	16 55	− 16.17	3
3817	Dec. 1	17 35	− 2.39	2

Mean = +4.76 km., r = ±4.0 km., r_1 = ±3.3 km.

Class, A2. Magnitude, 5.7. Owing to the small weight of each plate it is very hard to say whether the star is a spectroscopic binary or not. Probably it is not. The computed radial velocity based upon group motion is −4.2 km.

γ ARIETIS N. (P. G. C. 422)

R. A. 1h 48m.0; Decl. +18° 48′.3

PLATE	DATE	GR. M. T.	VELOCITY	WT.
		h m	km.	
3691	1916 Sept. 18	17 25	+ 2.99	6
3692	Sept. 18	18 22	− 6.94	6
3702	Sept. 24	17 30	− 1.52	11
3718	Oct. 1	16 30	−15.73	8
3719	Oct. 1	17 0	−13.50	8
3725	Oct. 2	18 33	−18.75	8
3739	Oct. 9	17 50	− 3.15	5
3752	Oct. 16	18 0	+ 2.10	4
3760	Oct. 22	15 35	−19.75	6
3767	Oct. 27	17 55	+ 1.25	6
3768	Oct. 27	18 25	+17.70	6

γ ARIETIS N. (P.G.C. 422) — CONTINUED

R. A. $1^h 48^m.0$; Decl. $+18\ 48'.3$

PLATE	DATE	GR. M. T.	VELOCITY	WT.
		h m	km.	
3772	Oct. 30	15 50	−19.73	5
3779	Nov. 5	13 55	− 8.97	8
3780	Nov. 5	14 25	+ 8.69	7
3781	Nov. 5	14 55	+15.82	8
3790	Nov. 10	15 45	− 9.42	8
3791	Nov. 10	16 15	+ 1.03	8
3799	Nov. 17	16 20	−10.07	6
3800	Nov. 17	16 50	− 3.12	6
3801	Nov. 17	17 20	+13.97	7

Mean = −1.86 km., r = ±1.8 km., r_1 = ±1.4 km.

Class, A. Magnitude, 4.9. It is interesting to notice how close this result is to other determinations. In *Astronomical Journal*, No. 669. Professor Boss mentions the observed radial velocity of γ Arietis as being −1.2 km. The computed radial velocity based upon a group motion of +21 kilometers relative to the sun is −1.6 km.

γ ARIETIS S. (P.G.C. 423)

R. A. $1^h 48^m.0$; Decl. $+18^\circ 48'.2$

PLATE	DATE	GR. M. T.	VELOCITY	WT.
		h m	km.	
3690	1916 Sept. 18	16 48	+16.68	9
3701	Sept. 24	16 57	+ 2.61	10
3705	Sept. 25	17 28	+ 0.87	9
3706	Sept. 25	18 0	− 1.34	5
3720	Oct. 1	17 45	− 2.24	13
3721	Oct. 1	18 45	+ 7.10	9
3726	Oct. 2	19 18	+ 6.30	8
3740	Oct. 9	18 53	+ 4.71	6
3753	Oct. 16	18 30	+ 9.61	9
3754	Oct. 16	19 15	+ 4.12	7
3765	Oct. 27	16 35	+ 2.45	9
3766	Oct. 27	17 5	+ 1.80	10

Mean = +4.29 km., r = ±1.0 km., r_1 = ±0.9 km.

Class, A. Magnitude, 4.7. The computed velocity based on group motion is −1.6 km.

The difference between the radial velocities of the two components of γ Arietis is very interesting, as well as their difference of spectra. These stars constitute the double star, Σ180, with position angle 359° and distance 8″.3. It was discovered as a double star by Hooke in 1664, the second to be seen by any observer. Burnham regarded the components as relatively fixed. The position angle has not changed appreciably since the first measurements were made. The distance seems to have decreased slightly, but not enough to render change altogether certain. According to Auwers the components have a common proper motion of 0″.113 in 147°.2. It is therefore probable that the two stars form a physical system. According to the *Preliminary General Catalogue* of Boss, the proper motions of these two stars are practically the same. The measured difference in radial velocity is probably not due to orbital motion of the visual pair. Possibly one star of the pair is a long period binary. If so, since the above velocity for the northern component agrees well with determinations of other observers, suspicion falls more strongly on γ Arietis, S.

PIAZZI 70 (P.G.C. 2773)

R. A. $10^h 21^m.5$; Decl. $+42^\circ 6'.7$

PLATE	DATE	GR. M. T.	VELOCITY	WT.
		h m	km.	
3822	1916 Dec. 17	16 50	+ 9.71	11
3823	Dec. 17	17 50	+ 3.55	10
3828	Dec. 23	16 30	+11.48	10
3830	1917 Jan. 5	15 55	+11.57	9
3831	Jan. 5	17 15	− 1.52	12
3832	Jan. 5	18 15	+ 5.38	11
3839	Jan. 7	16 8	+15.53	7
3840	Jan. 7	17 25	+ 5.44	12
3850	Feb. 18	17 10	−10.52	2
3851	Feb. 20	18 45	+ 2.18	12

Mean = +6.06 km., r = ±1.2 km., r_1 = ±1.2 km.

Class, A. Magnitude, 6.2. The velocity obtained at the Mount Wilson Observatory is +5.2 km. It agrees well with the velocity obtained here. The radial velocity deduced from the group motion is −1.0 km.

θ LEONIS (P.G.C. 2974)

R. A. $11^h\ 9^m.0$; Decl. $+15°\ 59'$

PLATE	DATE	GR. M. T.	VELOCITY	WT.
		h m	km.	
3465	1916 Apr. 1	17 8	+ 4.69	49
3466	Apr. 1	18 0	+ 6.51	50
3503	Apr. 29	16 13	+10.59	25
3513	June 7	15 33	+21.98	25
3514	June 7	16 13	+10.08	22
3515	June 7	16 33	+ 7.52	18
3516	June 11	14 53	+19.57	24
3517	June 11	15 38	+10.16	20
3523	June 21	14 43	+11.82	22
3533	June 30	15 2	+20.85	17

Mean = +11.08 km., r = ±1.3 km., r_1 = ±0.6 km.

Class, A. Magnitude, 3.3. This value differs from that given in Boss's note in the *Astronomical Journal*, No. 699, which is +6.8 km. It is probable that the star is a spectroscopic binary but this is difficult to decide from the present observations. If it is, it has probably a period of only a few hours. My provisional velocity deduced for the center of mass does not agree with the velocity +4.0 km. deduced from the group motion.

BRADLEY 1555 (P.G.C. 2987)

R. A. $11^h\ 13^m.7$; Decl. $+38°\ 44'$

PLATE	DATE	GR. M. T.	VELOCITY	WT.
		h m	km.	
3467	1916 Apr. 1	19 5	+ 3.54	14
3841	1917 Jan. 7	18 45	+ 9.35	8
3853	Feb. 27	17 40	− 0.63	6
3860	Mar. 2	15 20	− 6.54	27
3861	Mar. 2	16 20	− 8.26	22
3862	Mar. 2	17 2	− 4.60	26
3867	Mar. 18	14 5	−25.35	12
3868	Mar. 18	14 45	−28.86	13
3869	Mar. 18	15 25	−29.41	14
3870	Mar. 18	16 5	−31.14	18

Class, A2. Magnitude, 4.8. This star was discovered to be a spectroscopic binary by Doctor O. J. Lee, at Yerkes Observatory, and was announced as such in *Science*, Vol. 28, page 853, 1908. The above observations confirm the velocity variation but do not suffice to determine the motion of the center of mass. The spectrum lines on the Ann Arbor plates are very diffuse at some phases and much sharper at others, suggesting that two similar stellar spectra are superposed and that they are oscillating mutually.

Further observations by the author, made at Lick Observatory, confirm the suggested existence of similar spectra of two components of a binary system in the light of this star. From measures of the magnesium line at λ 4481 on twenty-six plates taken by the writer at the Lick Observatory in the summer of 1917, a center of mass velocity of − 3 km. has been derived for the system. (*Popular Astronomy*, Vol. XXVII, page 29.) The computed velocity of the center of mass based on the group motion is − 2.3 km.

PARIS 14287

R. A. $11^h\ 36^m.9$; Decl. $+22°\ 47'$

PLATE	DATE	GR. M. T.	VELOCITY	WT.
		h m	km.	
3898	1917 Apr. 8	14 57	−20.67	6
3899	Apr. 8	16 2	−17.68	10
3900	Apr. 8	17 10	−28.97	6
3901	Apr. 9	15 17	−21.55	16
3902	Apr. 9	16 32	−25.53	23
3903	Apr. 9	17 47	−16.61	12
3905	Apr. 10	15 5	−18.07	7
3906	Apr. 10	16 15	−22.84	9
3908	Apr. 14	15 27	−22.10	6
3909	Apr. 14	16 50	−42.52	7

Mean = −23.22 km., r = ±1.4 km., r_1 = ±1.3 km.

Class, A. Magnitude, 6.5. The velocity deduced from group motion is +0.6 km.

PIAZZI 202, OR PARIS 14608

R. A. $11^h\ 53^m.0$; Decl. $+32°\ 50'$

PLATE	DATE	GR. M. T.	VELOCITY	WT.
		h m	km.	
3884	1917 Mar. 25	17 5	− 1.89	13
3885	Mar. 25	18 5	+ 5.24	13
3886	Mar. 29	15 35	+11.02	16
3890	Apr. 2	14 50	+ 6.11	13
3891	Apr. 2	16 27	+12.33	14
3892	Apr. 2	17 52	+ 4.51	12
3894	Apr. 3	15 10	− 0.36	11
3895	Apr. 3	16 10	− 7.86	13
3896	Apr. 3	17 2	− 4.66	15
3897	Apr. 6	18 12	+ 5.33	14

Mean = +3.17 km., $r = \pm 1.4$ km.

Class, A. Magnitude, 6.3. There is some indication in the above measurements that this star is a spectroscopic binary. If so, the radial velocity of its center of mass may be said to be approximately +4.3 km. This velocity computed on the basis of group motion would be − 2.9 km.

P. G. C. 3459

R. A. $13^h\ 16^m.6$; Decl. $+2°\ 36'.8$

PLATE	DATE	GR. M. T.	VELOCITY	WT.
		h m	km.	
3904	1917 Apr. 9	19 25	− 4.47	4
3907	Apr. 10	17 45	− 7.55	4
3910	Apr. 15	15 25	+10.10	3
3911	Apr. 15	16 5	− 4.96	3
3912	Apr. 15	16 45	− 5.80	3
3916	Apr. 24	14 40	+ 5.42	3
3930	May 13	16 10	−26.22	3
3931	May 13	16 50	+ 0.38	3
3932	May 13	17 30	−11.31	3

Mean = −2.67 km., $r = \pm 2.5$ km., $r_1 = \pm 4.1$ km.

Class, A. Magnitude, 5.8. The velocity computed on the basis of group motion is −1.3 km. The measurement of these plates was extremely difficult since only a few broad and diffuse lines were available.

GROOMBRIDGE 2044 (P. G. C. 3552)

R. A. $13^h\ 42^m.0$; Decl. $+41°\ 35'.4$

PLATE	DATE	GR. M. T.	VELOCITY	WT.
		h m	km.	
3504	1916 June 3	17 54	+ 4.24	7
3518	June 11	16 45	− 4.48	6
3519	June 11	18 0	+ 0.29	3
3521	June 15	15 20	+ 5.51	4
3522	June 19		−14.63	9
3528	June 25	15 40	−20.18	7
3541	July 2	15 14	−12.89	6
3871	1917 Mar. 20	18 20	−39.42	5
3872	Mar. 21	19 45	−30.20	10
3873	Mar. 21	20 45	−23.42	9

Mean = −15.69 km., $r = \pm 2.9$ km., $r_1 = \pm 1.3$ km.

Class, A. Magnitude, 6.0. There is some evidence that this star is a spectroscopic binary. The velocity of its center of mass computed on the basis of group motion is − 10.9 km.

In the accompanying table the available velocity data relating to the stars in Boss's Antapex Group are assembled so far as the writer knows them. In the first column, the star numbers with two exceptions are those of Boss's *Preliminary General Catalogue*. The fourth column contains the velocities, referred to the sun, determined by the writer except for the first star. Binary stars are indicated by a B following the velocity, with a question mark added if the binary character is in doubt. For the one established binary the velocity was obtained from single-prism spectrograms made at the Lick Observatory. The fifth column contains the probable errors computed from the plate residuals, and the sixth column, the velocities determined by other observers. The velocity for No. 2773 in this column was determined at Mount Wilson; the others are taken from the table by Boss in *Astronomical Journal*, Volume 28, page 174. The source of these latter velocities seems mainly to be *Lick Observatory Bulletin* No. 211, but star No. 107 is credited with a velocity of + 14.0 km. in that *Bulletin* and with a velocity of + 9.0 km. by Boss; and star No. 885 is found elsewhere. In column seven the mean velocities based on

VELOCITY AND OTHER DATA ON BOSS'S ANTAPEX GROUP

STAR	R. A. 1900.0	DECL. 1900.0	VELOCITY	PROB. ERROR	VEL. BY OTHER OBS.	MEAN VEL.	COMP. VEL.	O_1-C_1	WT.	O_2-C_2
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
	h m	° ′	km.	km.	km.	km.	km.	km.		km.
5944	22 59.8	+14 40	− 3.2	±0.8		− 3.2	−11.7	+ 8.5	1.6	+5.5
6031	23 21.8	+ 0 42	− 3.3	±0.9	− 3.7	− 3.4	− 7.4	+ 4.0	1.5	+0.7
101	0 27.0	−63 31			+12	+12	+10.7	+ 1.3	0.5	−3.3
107	0 28.2	−63 35			+ 9	+ 9	+10.8	− 1.8	0.5	−6.3
249	1 2.6	+20 12	+ 4.8	±4.0		+ 4.8	− 4.2	+ 9.0	0.2	+5.5
422	1 48.2	+18 48	− 1.9	±1.8	− 1.2	− 1.6	− 1.6	0.0	1.0	−3.7
423	1 48.2	+18 48	+ 4.3	±1.0		+ 4.3	− 1.6	+ 5.9	1.0	+2.1
885	3 44.9	−37 56			+17	+17	+16.3	+ 0.7	0.5	−4.3
2773	10 21.5	+42 7	+ 6.1	±1.2	+ 5.2	+ 5.7	− 1.0	+ 6.7	1.0	+3.0
2974	11 9.0	+15 59	+11.1 B?	±1.3	+ 6.8	+ 9.0	+ 4.0	+ 5.0	1.0	−0.9
2987	11 13.7	+38 44	− 3 B			− 3.0	− 2.3	− 0.7	1.0	−4.3
Paris 14287	11 36.9	+22 47	−23.2	±1.4		−23.2	+ 0.6	−23.8	0.7	
Pi 202	11 53.0	+32 50	+ 3.2 B?	±1.4		+ 3.2	− 2.9	+ 6.1	0.8	+2.5
3459	13 16.6	+ 2 37	− 2.7	±2.5		− 2.7	− 1.3	− 1.4	0.2	−5.2
3552	13 42.0	+41 35	−15.7 B?	±2.9		−15.7	−10.9	− 4.8	0.3	−8.0

columns four and six are given. In the four cases for which velocities were combined into a mean, there was very satisfactory agreement between the two determinations except in the case of star No. 2974 (θ Leonis), and it is significant that this star shows other evidence of binary character. The means were influenced slightly by the writer's judgment of the relative value of the observations combined. In column eight, velocities are given computed on the basis of a stream velocity of 21 kilometers relative to the sun toward an apex in right ascension, 107°, and declination, − 40°. Column nine contains the differences between the corresponding velocities in columns seven and eight, in the sense, observed minus computed. In column ten weights are assigned to the velocities in column seven. These weights are based on the probable errors in column five, the weights in the tables for the several stars in earlier pages of this paper, and particularly in the case of observations other than his own, on the writer's judgment, as influenced by available facts.

It will be best to examine the data in this table from the stand-point of Boss's convergent and stream velocity and then to consider the possibility of finding better constants of the group motion, if such there be. In the first place, a glance at the quantities in column nine reveals an outstanding residual in the case of the star, Paris 14287, indicating clearly that this object may be eliminated from further consideration in connection with the supposed group. A survey of the rest of the residuals in this column reveals a striking preponderance of positive quantities, especially among those based on the writer's velocities. This might suggest that a positive systematic difference, due perhaps to personal equation, affects the writer's values. This idea carries some weight because a comparison of the writer's velocities of σ Cygni with those obtained at Lick Observatory reveals a systematic difference of about the magnitude and sign indicated here. But a comparison of the writer's velocities with those of other observers in this table reveals no such effect except in case of the possible binary, θ Leonis. A smaller preponderance of positive residuals is found for the six stars employed by Boss to derive the group velocity. The mean of his residuals in the sense, observed minus com-

puted, is + 1.2 km. Three of these six residuals are evidently weak; the other three average +2.2 km.; and if the suspected binary, θ Leonis, be omited the remaining two average +2.1 km. These facts, however meager the data, suggest that a K term is involved here. The straight mean of the fourteen residuals in column nine is +2.8 km., and the weighted mean +4.1 km. Apparently an effect due to a K term is present here, and obviously with the data now available a new solution for the elements of the group motion including a K term is desirable. Such a solution seems to be justified also by a further examination of the data which is described in the next paragraph.

We may consider the data as they stand in the table in their bearing on the group theory from the standpoint of probable errors of the observed velocities. For the ten stars (excepting Paris 14287) having probable errors, we find that the residual based on group motion is more than five times the probable error in three cases, more than four times the probable error in two other cases, more than three times the probable error in one other case, and actually less than the probable error in only two cases. If, however, we remove the systematic element from the residuals for these stars as well as we can at this juncture by subtracting out their mean of +4.8 km., the case for group motion is much improved. There is then but one residual exceeding four times the corresponding probable error; one other exceeding three times its probable error; and only two others exceeding twice their probable errors.

Again if we consider the quantities in column nine to be actual errors of observation it should be possible to derive from them probable errors of a velocity determination of weight unity in fair agreement with the probable errors in column five. If this be done for the writer's velocities the probable error for an observation of weight one is ±3.8 km. (omitting Paris 14287) or omitting the three suspected binaries, ±4.0 km. This result is about three times as large as we should expect on the basis of true stream motion. If, however, we correct the residuals for the systematic element as above, the probable error derived from them of a determination of weight unity, on the scale of column ten, is ±2.3 km. These results lend support to the conclusion that the motion of these stars is related in some way as Boss has proposed.

The average of the absolute values of the residuals $O_1 - C_1$, in column nine of the table is 4.0 km. or, if a systematic term of +2.8 km. be subtracted out, 3.7 km. This is far less than the residual velocities of stars of Classes A0 to A2 should be on the average. Apparently there is indication of stream motion here.

New elements of the motion of the Antapex group on the basis of fourteen velocities in the accompanying table may be computed if Boss's convergent be assumed and an equation of condition be written for each star of the form,

$$V_0 \cos d + K - V = 0,$$

in which V_0 is the group velocity; V is the star's observed velocity; d is the angular distance of the star from the vertex or convergent; and K is a constant assumed to represent any systematic error to which the observed radial velocities are liable.

A least squares solution of the resulting fourteen equations gives the following normal equations,

$$1.048\ V_0 - 0.908\ K = 20.11,$$
$$0.908\ V_0 - 11.100\ K = 21.55.$$

which gives us the values,

$$V_0 = +22.5 \text{ km.} \pm 0.8 \text{ km.},$$
$$K = +3.78 \text{ km.} \pm 0.23 \text{ km.}$$

The value of V_0 agrees well with Boss's value of +21 km. based on more limited data. The large value of K above is probably due in large part to the systematic tendency toward positive values in the writer's radial velocities determined at Ann Arbor as brought out by a comparison of his velocities of σ Cygni with those made at the Lick Observatory. Some part of this value of K is probably accounted for by a small real K term for Class A stars, indicated in studies by Campbell.

In the last column of the Table of Velocity and Other Data, the differences are given between the observed velocities of the fourteen stars and the velocities computed for them with the values

of V_3 and K derived here and referred to Boss's convergent at right ascension, 107°, declination, −40° for 1875.0. The weighted average of the absolute values of these residual velocities is 3.3 km. This is far less than the expected residual radial velocity of stars with spectra in Class Ao and A2. Apparently the deductions by Boss with reference to the probable existence of an Antapex Group of brighter stars, nearly at rest with reference to our system, are well sustained.

My thanks are due to Doctor R. H. Curtiss whose interest and help in my work at Ann Arbor I greatly appreciate.

Ann Arbor, Michigan, 1917.

SPECTROGRAPHIC STUDY OF THE EARLY POTSDAM VELOCITY STARS, NOT KNOWN TO BE BINARIES

By LEWIS L. MELLOR

INTRODUCTION

For twenty-seven years, from their beginning in 1863 until 1890, the attempts of several observers of great skill to determine by visual methods the radial velocities of stars through the application of Doppler's principle produced no reliable result. The uncertainties of the observed velocities were much greater than the average quantities to be measured. Finally, in 1890, Keeler secured at the Lick Observatory, with considerable difficulty, notwithstanding many favorable circumstances, trustworthy radial velocities determined visually for three bright stars. In the meantime, beginning in 1888, Doctor H. C. Vogel, at Potsdam, in collaboration with his colleague, Doctor J. Scheiner, had undertaken a program of photographic observation of stellar spectra, which yielded for fifty-one stars radial velocities so accurate and so easily obtained that visual observations were no longer to be thought of in this field. With Keeler's very limited visual program at the Lick Observatory, the Potsdam velocities of fifty-one stars, determined in the years 1888 to 1891, constitute our earliest reliable data of this kind and for this reason are of especial value. The fifty-one stars studied by Vogel and Scheiner in their first photographic radial velocity program are referred to in the title of this paper as "The Early Potsdam Velocity Stars."

The spectrographic work inaugurated at Potsdam was taken up within a few years at other observatories with more powerful telescopes, notably the Pulkowa and Lick refractors, and methods were improved until, by virtue of superior apparatus and technique, a single spectrogram, made in much less time than Vogel and Scheiner required, yielded for the average case a more accurate velocity than could be derived from twenty or more of the earlier Potsdam photographs. The study of the velocities of the brighter stars was then pursued quite vigorously at various observatories with the result that at present an exceedingly valuable store of stellar radial velocity data is available.

In the study of the brighter stars, which were attacked first, the spectrograph with a dispersion of three dense prisms of approximately sixty degrees angle was generally preferred because for such brighter objects a spectrograph of this dispersion represented about the best compromise between power and long exposure for the large modern telescope. Single-prism stellar spectrographs were used successfully at Potsdam as early as 1892, and at Cambridge, England, in 1897. It was soon recognized that velocities of great value for relatively faint stars, as well as bright ones, could be determined with spectrograms of one prism dispersion. Professor W. W. Campbell, in 1901, obtained very satisfactory velocities of 1830 Groombridge with a single prism instrument at Lick Observatory. And, in 1903, Professor R. H. Curtiss made successful observations with the same instrument for the determination of the velocity curve and orbit of the relatively faint variable star, W Sagittarii. In connection with this study Professor Curtiss devised a method, employed below, which yielded velocities from single prism spectrograms of such accuracy for solar type spectra that it became evident that the low dispersion spectrograph would be of great service in the study of faint stars, even when nearly all the lines were blended. In the study of spectra with a few isolated lines, especially when such lines are ill-defined, the single-prism instrument has been especially useful. Probably in this province it has found its most productive application. But in many directions the low dispersion stellar spectrograph has been found valuable and it is important that its applicability should be thoroughly investigated.

One of the first programs planned for the single-prism spectrograph of the Astronomical Observatory of the University of Michigan was the observation of a list of standard velocity stars in order to test the accuracy and reliability of the new instrument and to determine the nature and magnitude of systematic errors affecting the installation, if such existed. The stars, not known to be binaries, in the early Potsdam program were selected for this study because velocity observations on them had extended over so long an interval, because in general they had been well observed, because they included representative spectra, and because it was thought that few binaries would be found among them. A few plates on this program were made in 1911, a few weeks after work with the new spectrograph began. Later the investigation was assigned to the writer, whose regular observations were begun early in 1912 and were continued for more than two years.

PURPOSE

It was the writer's purpose in the present paper to discuss the application of the single-prism spectrograph and $37\frac{1}{2}$-inch reflector of the Detroit Observatory to the study of the spectra and radial velocities of those of the early Potsdam velocity stars, referred to above, which were not known to be binaries in 1912, when the observations of this program had begun. In connection with this study the writer had the following aims in view.

1. To determine by measures of a number of spectrograms the radial velocities of these stars for the present epoch in order to add to our knowledge of these important objects and to bring out evidence of velocity variation, if such exists.

2. To establish for a given observer the systematic difference between velocities obtained with the Detroit Observatory equipment and those obtained at other observatories for a group of stars with representative spectra which has been long and widely observed with instruments of different dispersions.

3. To provide for use in this Observatory a set of plates of known systematic divergence from the average of the determinations of other observers with other equipment.

4. To study the wave-lengths of the lines in the spectra of these stars, more especially to assist in coördination of wave-length with spectral type and to facilitate the elimination of useless blends.

5. To study any peculiarities that may be observed in connection with the structures of lines and other spectral features.

6. To investigate the accuracy of wave-length and velocity results obtained for stars of various types with the Ann Arbor Observatory equipment, which is typical perhaps of the combination of modern single-prism spectrograph and reflecting telescope of moderate size.

7. To study sources of error which may obtain in the preparation and measurement of spectrograms and especially the magnitude and character of the errors due to distortion of the star image caused by atmospheric dispersion and changes in mirror temperature, guiding errors, and inexperience of the measurer at the measuring engine.

INSTRUMENTS

The $37\frac{1}{2}$-inch reflector and single-prism spectrograph employed in this study have been described fully in the first volume of these *Publications*. The entire set of spectrograms discussed in this paper is homogeneous so far as instrumental conditions are concerned. Throughout the work the titanium spark was used as the comparison source.

The important features of the measuring engine have been mentioned by me in Volume I, page 142, of these *Publications*. Soon after this engine was completed the periodic error of the screw, over a distance corresponding to ten complete revolutions, was investigated by me and was found to be not more than 0.34 of the estimated tenth of a division of the head. On four different occasions during the measures of the program of the Potsdam stars, the screw error was re-determined. The amplitude of the error curve for the first three determinations remained nearly constant, and for the last it was sensibly zero. The engine apparently improved with use.

METHODS OF MEASUREMENT

All plates were measured direct and reversed. Microscope powers, ranging from six to perhaps fifteen, were found useful, but one magnification only was used for the study of any one star. In the measurement of the comparison spectra the writer made settings nearly half way between the ends of the lines, and for this point the average correction due to curvature was about 1.8 kms. Settings on star lines were made in their centers of density.

METHODS OF REDUCTION

In the reduction of the spectrograms discussed in this paper two different methods were employed depending upon the character of the star's spectrum.

For spectra containing a considerable proportion of isolated lines in Classes Bo to Fo inclusive, the method based on the Hartmann interpolation formula was used. Adopting the best available laboratory wave-lengths, a fundamental table was prepared giving the relative positions of many star and comparison lines for zero relative velocity. In the reduction of any star plate for radial velocity the measures were first reduced to the dispersion and zero of the fundamental table using the comparison lines. The remaining differences between the micrometer readings of the same lines in the measures of the star spectrum and in the standard table were attributed to relative velocity and curvature and were converted into velocity in kilometers per second by a simple application of the Doppler-Fizeau principle. Correction for the curvature of the spectrum lines and the velocity of the observer due to the revolution and rotation of the earth were then applied to reduce the velocities to the sun in which form they are published below. The details of the determination of the Hartmann interpolation formulæ and the correction curves used in this study have been published by the writer in Volume I, page 142 et seq., of these *Publications*.

For stellar spectra containing many lines, most of which were blends, (Classes F5 to Mb inclusive), the so-called Zero Standard Method proposed by Professor Curtiss was used. In this method the fundamental table is prepared by measuring the stellar and comparison lines on several spectrograms of an object of known velocity such as the sun or moon. These measures when reduced to the same dispersion and zero are combined into one table by taking means of the measures of the same line on the several plates. This table then gives for the spectrograph and measuring engine employed the relative positions of star lines and comparison lines for a known small velocity. Corrected to zero velocity, this table may be used in the reduction of star plates in the manner described for the fundamental table based on wave-lengths and the Hartmann interpolation formula, except that in this case no correction for curvature is necessary.

In any given star the actual wave-length or standard micrometer reading may vary from the assumed value. To reduce the effect of such deviations on the several velocities the writer has corrected for each star the assumed wave-lengths by amounts sufficient to reduce to zero the weighted mean of the residuals for each line on all of the plates of that star. New wave-lengths derived for the lines of each star in this way are discussed below.

THE OBSERVING LIST

The Potsdam velocity stars, fifty-one in number, were observed photographically by Vogel and Scheiner during a period of three years, from 1888 to 1891. The spectrograms were measured independently by both observers. The final results of their researches are described in detail in the seventh volume of the *Publikationen des Astrophysikalischen Observatoriums zu Potsdam*. In this list of fifty-one stars, Vogel and Scheiner found but one object, the variable star Algol, to have a variable velocity. Subsequent observations have shown that more than half are binaries. The accompanying observing list of twenty-six stars includes all those of the original Potsdam program not known to be binaries when the program was adopted. Their velocities are discussed in this paper. Two stars not in the list, α Pegasi and γ Orionis, were observed also, but because of their binary character will be considered elsewhere. The publication of

the velocities of the binary, β Libræ, which is found in the list, will be left for a future paper.

Twenty spectrograms were made of each of the stars with spectra in the Classes Bo to Fo except in the case of β Libræ for which many more were secured. Ten were secured for the stars with spectra in Classes F5 to M, except in the case of β Cassiopeiæ for which fifteen were obtained.

The positions of the stars in the *Observing List* are for the epoch 1900.0.

OBSERVING LIST

NAME	VIS. MAG.	R.A. (1900)	DECL. (1900)	SPECTRAL CLASS
β Cassiopeiæ	2.4	0^h $3^m.8$	+ 58° 36′	F5
α Cassiopeiæ	2.5	0 34 .8	+ 55 59	Ko
γ Andromedæ	2.3	1 57 .8	+ 41 51	K
α Arietis	2.2	2 1 .5	+ 22 59	K2
α Persei	1.9	3 17 .2	+ 49 30	F5
α Tauri	1.1	4 30 .2	+ 16 19	K5
β Tauri	1.8	5 20 .0	+ 28 31	B8
ζ Orionis	2.0	5 35 .7	− 2 00	Bo
α Canis Minoris	0.5	7 34 .1	+ 5 29	F5
β Geminorum	1.2	7 39 .2	+ 28 16	Ko
α Leonis	1.3	10 3 .0	+ 12 27	B8
γ Leonis	2.6	10 14 .5	+ 20 21	Ko
δ Leonis	2.6	11 8 .8	+ 21 4	A2
β Leonis	2.2	11 44 .0	+ 15 8	A2
γ Ursæ Majoris	2.5	11 48 .6	+ 54 15	Ao
η Ursæ Majoris	1.9	13 43 .6	+ 49 49	B3
α Bootis	0.2	14 11 .1	+ 19 42	Ko
ϵ Bootis	2.7	14 40 .6	+ 27 30	Ko
β Ursæ Minoris	2.2	14 51 .0	+ 74 34	K5
β Libræ	2.7	15 11 .6	− 9 1	B8
α Serpentis	2.8	15 39 .3	+ 6 44	Ko
α Lyræ	0.1	18 33 .6	+ 38 41	Ao
α Aquilæ	0.9	19 45 .9	+ 8 36	A5
γ Cygni	2.3	20 18 .6	+ 39 56	F8
ϵ Pegasi	2.5	21 39 .3	+ 9 25	Ko
β Pegasi	2.6	22 58 .9	+ 27 32	Mb

VELOCITIES OF STARS WITH SPECTRA IN CLASSES BO TO FO

The velocity results with other relevant data are found for stars with spectrum in Classes Bo to Fo in Tables 1 to 9 below. In the several columns in order from left to right are found the plate number, the Greenwich mean time, the velocity in kilometers per second reduced to the sun, the sum of the weights assigned to the individual lines during measurement, the probable error based on the internal residuals of the plate, the number of lines measured, the exposure time in minutes, the emulsion whether Seed lantern slide or Seed 23, and the seeing on a scale from 1 (poor) to 5 (excellent).

Following each table the weighted mean velocity is given with the velocity range and probable errors. Comparisons of the writer's results with those of other observers are also appended.

Of the probable errors, E_1 is the average probable error of a plate of average weight, determined for any star by taking the mean of the several values in the column headed P. E. in its table. Thus E_1 is based on internal residuals only. E is the probable error of a plate of average weight deduced in the usual way from the residuals from the mean of all the plates of any

star. E_2 is the square root of the difference between the squares of E and E_1. It is the element of the probable error due to variable instrumental errors, variation in personal equation, velocity variation, etc. For extensive lists of velocities, we should expect E_2 to be approximately constant for different stars except in cases where actual velocity variations enter in. If then E_2 is clearly larger in any case than experience would lead us to expect, this condition may be taken as an indication of variable velocity.

The descriptions of the spectra and the tables of velocities, with appropriate discussions, are found below.

β TAURI

R. A. $5^h\ 20^m.0$; Decl. $+28°\ 31'$

The spectrum of β Tauri is classified as B8 and contains the well known lines characteristic of this type. With the possible exception of α Lyræ, the spectrograms of β Tauri yield more reliable velocities than any of the other early type stars considered in this list, although all of the lines are diffuse.

TABLE 1

PLATE	GR. M. T.	VEL.	p.	P. E.	n.	EXP.	EM.	S.
438	1912 Apr. 10.532	+ 6.1	17	±1.75	14	10	LS	4
1164	Oct. 2.933	+ 1.4	24	1.41	19	13	LS	4
1165	2.942	− 0.3	21	2.01	15	13	LS	4
1391*	29.796	+12.0	12	1.23	10	6	23	3
1473	Nov. 15.853	− 1.7	9	1.39	5	9	LS	3
1474	15.860	− 4.3	13	2.17	8	9	LS	3
1523	29.844	+ 4.6	11	1.55	5	8	LS	3
2347	1913 Oct. 3.866	+ 4.3	18	2.60	9	2	LS	3.5
2348	3.879	+ 7.8	20	2.28	11	2	LS	3.5
2429	Nov. 4.763	+ 6.7	15	2.40	9	4	LS	2
2434	5.765	+11.2	13	1.66	9	3	LS	2
2435	5.778	+ 9.9	17	2.30	9	2	LS	2
2448	24.756	+ 6.1	18	1.92	14	2	LS	2
2449	24.774	+ 3.6	20	2.36	14	2	LS	2
2458	Dec. 3.742	− 0.5	14	2.98	13	6	LS	2.5
2459	3.747	+ 0.9	11	1.44	11	6	LS	2.5
2474	8.777	+ 1.2	19	1.53	14	3	LS	2.5
2475	8.789	+ 7.0	16	1.11	14	3	LS	2.5
2483	10.767	+ 7.3	17	1.97	14	2	LS	3
2484	10.781	+ 8.7	17	±2.98	13	2	LS	3

*Plate by Crump and Hess.
Average weighted velocity = + 4.6 km. ± 0.65 km.
Velocity range = 16.3 km.
$E_1 = \pm 1.96$ km., $E = \pm 2.84$ km., $E_2 = \pm 2.04$ km.

PUBLISHED VELOCITIES		MELLOR — PUBL. VELOC.
Vogel	+ 9.0 km.	−4.4 km.
Scheiner	+ 7.0	−2.4
Lick and Yerkes	+11	−6.4

The mean Ann Arbor velocity differs considerably from those deduced by other observers; and, moreover, the value of E_2 is larger than one would expect to derive from spectrograms of this quality. Accordingly, the possibility of a variation in the radial velocity of β Tauri at once presents itself. The diffuse lines in the blue region of the spectrum, and especially the K line of calcium, seem to be somewhat broader on some plates than on others, possibly due to the presence of a faint component.

A plot of the Ann Arbor velocities suggests the possibility of a variation of 15 or 20 kilometers range, with a period in the neighborhood of forty days, with some possibility of a short period. Professor Frost has very kindly sent me five velocity determinations of this star made at the Yerkes Observatory, between the years 1902 and 1911, inclusive, which are not inconsistent with variability. The velocities at hand, however, are not sufficient for a further study of the possible binary character of β Tauri.

ζ ORIONIS

R. A. $5^h\ 35^m.7$; Decl. $-2°\ 0'$

The spectrum of ζ Orionis, which belongs to Class Bo, is characterized by the sharpness of the K line of calcium, although the remaining more conspicuous lines are very broad and ill defined. The H and Hϵ lines are resolved on our spectrograms, but these were not used on account of diffuseness. The lines in the spectrum of ζ Orionis are much inferior to those observed in the case of β Tauri.

TABLE 2

PLATE	GR. M. T.	VEL.	p.	P. E.	n.	EXP.	EM.	S.
1188	1912 Oct. 4.950	+14.9	13	±1.91	11	6	LS	3.5
1475	Nov. 15.886	+27.4	14	4.79	10	9	LS	3
1476	15.894	+23.2	12	2.34	12	9	LS	3
1526	29.892	+28.0	20	2.24	15	8	LS	2.5
1527	29.899	+25.3	10	1.46	10	8	LS	2.5
2460	1913 Dec. 3.760	+17.7	13	3.16	12	9	LS	2.5
2461	3.778	+28.2	13	3.67	13	9	LS	2.5
2476	8.800	+19.2	15	3.97	11	4	LS	2.5
2477	8.812	+18.0	11	3.29	11	5	LS	2.5
2487	10.819	+ 7.3	9	1.73	9	2.5	LS	3
2488	10.824	+19.5	9	3.68	9	2.5	LS	3
2536	1914 Jan. 13.648	+23.8	12	1.49	12	4	LS	2
2537	13.672	+31.5	19	2.86	14	8	LS	2
2545	17.694	+ 4.3	9	3.20	10	9	LS	2
2558	Feb. 4.685	+11.2	11	2.53	10	8	LS	2
2575	11.650	+10.0	12	3.41	11	5	23	1
2576	11.665	+11.7	10	2.82	10	5	23	1
2597	24.651	+ 9.1	16	2.74	14	5	LS	2.5
2598	24.662	+ 9.5	10	3.47	10	4	LS	2.5
2632	Mar. 13.599	+22.9	22	±3.79	11	2.5	LS	2

Average weighted velocity (without K line) = +19.3 km. ±1.14 km.
Velocity range = 23.9 km.
$E_1 = \pm 2.92$ km., $E = \pm 4.99$ km., $E_2 = \pm 4.05$ km.

	PUBLISHED VELOCITIES		MELLOR — PUBL. VELOC.
Vogel	+17.1 km.		+2.2 km.
Scheiner	+12.6		+5.7
Lick Observatory	+17.5		+1.8
Frost	+22.7	(2 plates)	−3.4
Adams	+16.5	(5 plates)	+2.8

Although the lines in the spectrum of ζ Orionis are far from being good, a study of the probable errors given above indicates that the star is a binary. Considering the data at hand, a period of about 19 days seems to satisfy the observations better than any other. The velocity range indicated is about twenty kilometers.

After the plates were measured it was noticed that the K line of calcium did not oscillate in parallel with the diffuse lines. In the determination of the final velocities, therefore, it seemed best that the results for this line should be segregated. The final velocity resulting from the use of the K line alone was found to be +10.3 km., or 9 km. smaller than the average weighted velocity obtained from the diffuse lines.

α LEONIS

R. A. $10^h\ 3^m.0$; Decl. +12° 27′

The spectrum of α Leonis is classified as B8. It contains fewer and much broader lines than β Tauri, of similar type. Its measurement is extremely difficult. On a few plates the K line of calcium, the helium line at λ 4471, and the magnesium line at λ 4481, together with one or two others, are faintly visible, but are not available for velocity determinations. The velocity for plate 1941 has not been included in the means.

TABLE 3

PLATE	GR. M. T.	VEL.	p.	P. E.	n.	EXP.	EM.	S.
314*	1912 Mar. 10.675	− 5.6	10	±6.44	5	6	23	3
352	16.740	+ 8.2	7	1.88	4	9	LS	2
353*	16.750	− 9.8	4	3.62	4	9	LS	2
400	27.783	−12.6	4	0.98	3	10	LS	3
406	29.698	+ 3.0	7	1.22	4	10	LS	1.5
407	29.714	+ 5.7	6	2.91	4	8	LS	1.5
1649	1913 Apr. 1.658	+12.7	9	9.19	5	1	23	2
1662	7.663	+ 8.0	6	1.70	4	2	23	1.5
1663	7.676	+ 1.9	6	5.81	4	2	23	1.5
1692	14.621	+13.9	7	3.46	4	1	LS	1.5
1693	14.635	− 8.5	10	5.92	5	2	LS	1.5
1753	28.637	− 0.9	9	3.25	5	6	LS	1
1754	28.648	+ 3.0	7	2.98	4	2	23	1
1755	28.651	− 6.2	9	4.21	5	2	23	1
1773	29.618	+ 3.5	6	4.61	4	1	23	2
1923	June 2.617	+16.5	3	6.06	3	1	23	2
1941	4.601	−35.5	5	5.70	3	2	23	2.5
1942	4.611	− 3.4	6	1.88	3	2	23	2.5
1993	13.604	− 3.1	2	6.63	2	4	23	2
1994	13.610	− 9.6	2	±9.35	2	5	23	2

*Hadley.

Average weighted velocity = + 1.2 km. ±1.2 km.
Velocity range = 26.3 km.
E_1 = ±4.30 km., E = ± 5.23 km., E_2 = ±2.99 km.

	PUBLISHED VELOCITIES	MELLOR — PUBL. VELOC.
Vogel	−8.5 km.	+ 9.7 km.
Scheiner	−9.8	+11.0

Because of the small number and the poor character of the lines available for measurement in the spectrum of α Leonis, the probable errors are affected with considerable uncertainty. The magnitude of E_2 is not sufficient to suggest variability in the velocity of this star. It has been found advantageous to overexpose the plates and measure them with a magnifying power of about six.

δ LEONIS

R. A. $11^h\ 8^m.8$; Decl. $+21°\ 4'$

The spectrum of δ Leonis belongs to Class A2. The hydrogen lines, and also the K line of calcium, are extremely broad and strong, and these together with the majority of the weaker lines on the average plate show duplicity in structure. The apparent doubling of the lines is plainly not due to the presence of two physically connected bodies, since no oscillatory variations are observed throughout the measures. The two components, although by no means sharply defined, show an average separation of about 1.9 angstroms. The separation of all measurable double lines was observed and plotted with respect to wave-length.

The curve defining well the relation, in the region considered, between the separation of com-

TABLE 4

PLATE	GR. M. T.	VEL.	p.	P. E.	n.	EXP.	EM.	S.
315	1912 Mar. 10.702	−32.8	6	±5.51	5	6	23	2
316	10.717	21.1	7	5.04	5	6	23	2
354	16.772	29.7	4	4.78	4	16	LS	2
355*	16.783	20.0	5	4.32	5	8	23	2
398	27.750	32.7	5	9.42	5	12	LS	3
399	27.764	18.4	5	3.99	5	12	LS	3
408	29.725	27.8	7	11.71	5	12	LS	1.5
409*	29.742	19.3	6	5.50	5	12	LS	1.5
1664	1913 Apr. 7.686	29.2	5	5.84	5	8	LS	2
1694	14.651	20.5	5	2.66	5	7	LS	2
1695	14.665	14.9	5	6.71	5	7	LS	2
1756	28.671	33.0	5	4.93	5	6	23	1
1757	28.684	20.6	6	11.76	5	6	23	1
1775	29.651	21.9	5	4.17	5	2	23	3
1776	29.660	20.9	6	3.67	5	2	23	3
1924	June 2.627	18.9	6	3.42	5	5	23	2
1925	2.638	33.4	5	6.12	4	5	23	2
1943	4.621	13.0	7	5.46	4	5	23	2.5
1944	4.628	13.7	5	2.30	4	5	23	2.5
1980	11.647	−19.4	2	±8.35	3	8	23	2

*Hadley.

Average weighted velocity = −25.0 km. ±1.12 km.
Velocity range = 20.4 km.
$E_1 = \pm 5.95$ km., $E = \pm 4.90$ km., $E_2 = \pm 3.4\sqrt{-1}$.

PUBLISHED VELOCITIES		MELLOR — PUBL. VELOC.
Vogel	−14.9 km.	−10.1 km.
Scheiner	−13.9	−11.1
Lick Observatory	−18	− 7.0

ponents and wave-length, is a straight line, the equation of which is

$$\Delta\lambda = 0.000833\ (\lambda - 2100),$$

where $\Delta\lambda$ is expressed in angstroms.

With reference to the breadth of spectral lines, it has been shown that when the pressure is increased, the width increases with the wave-length. In the case under consideration the separation of the components, as shown by the above formula, increases linearly with increasing wave-length. From the equation of this line, given above, the separation of the components for any region in the spectrum may be computed.

In the spectrum of δ Leonis, although the lines are too diffuse to bring this out clearly, it seems reasonable to believe that the two dark components of any line are divided, and perhaps unsymmetrically, by a bright reversal. Such a peculiarity was found also in the spectra of β Leonis and α Aquilae, which are discussed below.

The lines of hydrogen, the K line of calcium, and the magnesium line at λ 4481, were the only ones used in the determination of the final radial velocities as given in Table 4, since for this purpose the remaining lines measured on the average plate were too unreliable for use in this connection.

A computation of the probable errors, as determined from the agreement of the velocities for the various plates, and from the agreement of the several lines on each plate, gives a value of E smaller than that of E_1, making E_2 imaginary.

The interagreement of the Ann Arbor velocities for this star is better than one would expect, considering the poor character of the lines measured, and is probably more or less accidental. Although the Ann Arbor velocities differ considerably from those of other observers, this is possibly attributable to the poor character of the spectrum lines and to the writer's systematic correction. There seems to be no evidence of variation in the Ann Arbor velocities themselves.

β LEONIS

R. A. $11^h\ 44^m.0$; Decl. $+15°\ 8'$

The spectrum of β Leonis, classified as A2, apparently exhibits a peculiarity very similar to that mentioned in the case of δ Leonis, although in the spectrum of β Leonis the metallic lines are not only more numerous but also much better defined. A close examination of the spectrograms of this star reveals the fact that several of the metallic lines are composed of two dark components which are separated by a bright reversal. Owing to the increased dispersion in the blue region of the spectrum, the well defined K line of calcium probably shows this effect much better than any other line. The stronger isolated lines show the reversal structure best.

As in the case of δ Leonis, it was first thought that the apparent doubling of these lines might be attributable to the presence of two bodies, but the results of measures made on various plates showed conclusively that the components did not oscillate with respect to one another. These measures give values of the separation of these double lines throughout the entire spectrum. The average separation at Hγ was observed to be about 1.8 angstroms.

The equation of the line expressing the relation between separation of components and wave-length is

$$\Delta\lambda = 0.001671\ (\lambda - 3268),$$

where $\Delta\lambda$ is given in angstroms. The slope of this curve is nearly twice as great as that obtained for δ Leonis. For a line at λ 4500 the separation of the two components in both cases is nearly of the same magnitude, while at λ 4000 there is a difference of nearly 0.4 angstroms. The relations involved are especially complicated because we are measuring the separation between components rather than the actual widths of the lines themselves. The separation of the components in all probability is more or less affected by the conditions of vapor density and temperature in the star's atmosphere, and, possibly, by Doppler effects due to convection currents and rotation. The absorption borders at the edges of emission lines in many spectra of Class Bp are probably of origin similar to that of the double absorption lines observed in β and δ Leonis, and α Aquilæ. In the spectrum of β Lyræ, Dr. Curtiss found a linear relation between separation of absorption borders and wave-length. The linear relation which he finds for a

number of Class Bp spectra between width of emission lines and wave-length is undoubtedly another aspect of the same phenomenon.

On the average twelve known lines were used in determining the radial velocity of this star, velocity determinations. Columns 3 and 4 give the relative weights of the unknown lines measured on the average plate, with the corresponding radial velocities.

TABLE 5

PLATE	GR. M. T.	VEL.	p.	VEL.	p.	P. E.	n.	EXP.	EM.	S.
345	1912 Mar. 15.788	+ 6.7	19	− 9.3	12	±2.24	9	8	LS	4
346†	15.796	− 7.6	17	− 4.0	12	1.66	10	10	LS	4
357*	16.824	+ 0.6	13	− 9.4	10	3.39	10	12	LS	2
360	19.742	− 9.9	8	+ 1.1	10	2.23	10	10	LS	3
367	19.753	− 3.0	19	− 4.9	16	3.01	15	10	LS	3
370	19.766	− 2.4	26	−10.4	11	6.14	11	10	LS	3
375*	22.781	− 7.2	23	−10.4	15	2.33	15	10	LS	3
410	29.757	+ 3.1	16	+ 1.1	15	2.34	13	10	LS	2
411*	29.771	+ 7.7	16	+ 1.5	11	1.37	11	10	LS	2
443	Apr. 10.732	− 2.9	13	+ 1.0	13	2.70	13	12	LS	3
1609	1913 Feb. 8.799	−11.1	15	− 8.9	9	4.16	9	6	LS	2
1610	8.842	− 7.7	14	− 6.3	13	2.46	13	7	LS	2
1641	Mar. 31.834	− 6.5	5	+ 0.4	13	2.12	13	6	23	1.5
1642	31.848	− 5.2	12	+ 5.2	15	2.89	14	5	23	1.5
1666	Apr. 7.714	− 8.7	19	− 8.0	13	2.12	13	7	LS	1.5
1696	14.679	−15.0	19	− 8.1	14	3.49	14	6	LS	1.5
1697	14.695	−23.3	6	−10.5	12	3.49	9	6	LS	1.5
1758	28.696	− 1.1	12	− 2.7	17	2.34	16	3	23	1
1759	28.709	− 4.7	12	−12.1	12	4.14	12	4	23	1
1945	June 4.537	− 1.3	9	− 1.1	13	2.01	13	3	23	2

*Hadley, †Curtiss.

Average weighted velocity (known) = − 4.6 km. ±0.8 km.
Velocity range = 17.3 km.
Average weighted velocity (unknown) = − 4.3 km.
Velocity range = 31.0 km.
Mean of known and unknown velocity = − 4.4 km. ±0.8 km.
$E_1 = \pm 2.77$ km., $E = \pm 3.46$ km., $E_2 = \pm 2.07$ km.

PUBLISHED VELOCITIES		MELLOR — PUBL. VELOC.
Vogel	−13.9 km.	+9.5 km.
Scheiner	−10.5	+6.1
Lick Observatory	+ 1.3	−5.7

on which the data in Table 5 depend. The wave-lengths of about an equal number of unknown lines measured on the average plate, were determined from the lines already known, and these too were used independently for

The lines in this star from their very nature are extremely difficult of measurement. The value of E_2 is not certainly larger than one would expect to obtain from a constant velocity star of this type.

γ URSÆ MAJORIS

R. A. $11^h\,48^m.6$; Decl. $+54°\,15'$

The spectrum of γ Ursæ Majoris belongs to Class Ao and contains the Huggins series of hydrogen, the K line of calcium, the magnesium line at λ 4481, and possibly a few very faint metallic lines. All of the lines in the spectrum of this star are extremely broad and ill defined. such that definite conclusions are unwarranted. A plot of the above results, obtained during the years 1912 and 1913, leaves open the possibility of a variation in the velocity of this star. No period could be deduced from the observations, but they were not well distributed in time.

It was thought that the K line of calcium varied slightly in width on different plates, and if it may be assumed that the velocity of this star is variable, this effect is perhaps explained by the presence of a faint component.

TABLE 6

PLATE	GR. M. T.	VEL.	p.	P. E.	n.	EXP.	EM.	S.
317*	1912 Mar. 10.736	−11.0	6	±6.02	4	6	23	2
318	10.744	−18.3	9	0.56	4	6	23	2
331*	12.769	−33.3	6	5.95	4	10	23	2
332*	12.778	−21.4	8	3.23	5	10	23	1
393	26.738	−12.8	8	3.08	4	6	LS	4
394	26.747	− 6.4	9	5.39	4	6	LS	4
419	Apr. 5.768	−10.0	9	2.36	4	12	LS	2
420*	5.782	−23.4	5	3.40	4	12	LS	2
433	7.727	− 5.5	5	6.39	3	12	LS	2
434	7.738	− 9.4	8	2.87	4	12	LS	2
445	10.788	+ 2.5	6	7.53	3	12	LS	3
1668	1913 Apr. 7.747	−16.7	7	2.06	5	9	LS	2
1669	7.763	−21.5	7	2.43	4	8	LS	2
1698	14.709	−16.2	7	1.76	4	8	LS	2
1699	14.728	−11.7	7	3.71	4	6	LS	2
1760	28.720	−14.7	9	3.54	4	5	23	1.5
1761	28.738	−14.7	8	1.92	4	5	23	1.5
1779	29.690	− 9.5	7	3.40	4	2	23	3
1780	29.702	− 9.8	7	3.16	4	2	23	3
2054	June 27.649	− 3.8	5	±4.17	4	3	23	2.5

*Hadley.

Average weighted velocity = −13.4 km. ±1.2 km.
Velocity range = 35.8 km.
E_1 = ±3.58 km., E = ±5.00 km., E_2 = ±3.49 km.

PUBLISHED VELOCITIES		MELLOR — PUBL. VELOC.
Vogel	−30.0 km.	+16.6 km.
Scheiner	−23.2	+ 9.8
Lick Observatory	− 9.0	− 4.4

The magnitude of the quantity E_2 suggests a possible variation in the velocity of γ Ursæ Majoris, but the character of the spectrum is

η URSÆ MAJORIS

R. A. $13^h\ 43^m.6$; Decl. $+49°\ 49'$

The spectrum of η Ursæ Majoris belongs to Class B3. Of the lines measured the majority are attributed to helium and hydrogen, the helium lines being more numerous. The carbon line at λ 4267, the magnesium at λ 4481, and the silicon at λ 4552 were also measured on one or more plates. The K line of calcium is barely visible, and the two silicon lines at λ 4128 and λ 4131, even on underexposed plates, are very faint and unmeasurable. All of the conspicuous lines appear rather broad and hazy, and thus very difficult of measurement.

The Ann Arbor velocities of η Ursæ Majoris are not in good agreement with the results obtained elsewhere. Although the radial velocity as given by the Lick Observatory depends upon but one observation on a difficult spectrum, it does not seem probable that the discrepancy between the above results can be attributed to systematic errors alone. This fact, together with a consideration of the relatively large value of E_2, seems to indicate that there is a variation in the velocity of this star. A plot of the observations for the year 1913 suggests a possible variation in its radial velocity. In the above observations the velocities seem to increase with time. Not enough observations are at hand, however, to show the range of its velocity variation.

TABLE 7

PLATE	GR. M. T.	VEL.	p.	P. E.	n.	EXP.	EM.	S.
395	1912 Mar. 26.770	0.0	8	±4.05	7	4	LS	4
396	26.776	− 1.6	5	6.04	4	4	LS	4
425	Apr. 5.863	− 2.0	5	4.08	4	8	LS	2
426*	5.874	+ 8.1	6	4.47	4	8	LS	2
458	23.733	+13.5	6	3.93	6	7	LS	3
459	23.740	+ 9.7	10	5.68	7	5	LS	3
477	26.776	− 1.1	9	6.01	6	6	LS	2
478	26.783	− 9.4	7	3.91	6	6	LS	2
491	30.728	+12.4	12	4.18	8	9	LS	3
492	30.737	+ 5.8	9	6.31	8	7	LS	3
1700	1913 Apr. 14.739	+ 2.6	9	4.01	6	3	LS	2
1701	14.760	+ 1.2	11	2.09	9	5	LS	1
1762	28.748	+19.6	8	6.77	6	2	23	1.5
1763	28.763	+ 5.6	9	4.20	6	2	23	1.5
1781	29.715	+17.9	9	2.85	6	1	23	3.5
1782	29.726	+11.3	5	6.04	4	1	23	3.5
1865	May 11.660	+22.9	6	10.63	4	1	23	3
1866	11.680	+15.8	4	3.93	4	1	23	3
1897	30.648	+23.6	11	1.87	7	2	23	3
2057	June 27.671	+28.6	9	±3.31	7	1	23	2

*Hadley.

Average weighted velocity = +9.5 km. ±1.5 km.
Velocity range = 38.0 km.
E_1 = ±4.58 km., E = ±6.76 km., E_2 = ±4.97 km.

PUBLISHED VELOCITIES		MELLOR — PUBL. VELOC.
Vogel	−28.7 km.	+38.2 km.
Scheiner	−23.8	+33.3
Lick Observatory	− 6.0 (One observation)	+15.5

β LIBRÆ

R. A. $15^h\ 11^m.6$; Decl. $-9°\ 1'$

The spectrum of β Libræ belongs to Class B8 and the measurable lines are those of the Huggins series of hydrogen. On underexposed plates there is a trace of the helium line at λ 4026, and the magnesium line at λ 4481. On account of the broad character of the hydrogen lines it was found desirable to overexpose the plates and measure them with a magnifying power of about six; in this way more consistent results were obtained.

As measured velocities from eight plates of this star taken during the year 1912 and twelve more during the following year gave a range of nearly fifty kilometers, it was thought that the velocity was variable. About the same time Lee announced a variation in the velocity of β Libræ on the basis of five plates, giving a range of fifty-three kilometers. Seventy-nine plates were made at Ann Arbor in 1914, between April 13 and July 20 inclusive, in order that an approximate period might be obtained; in 1915 ten additional plates were taken. The error curve as a criterion for the detection of variable velocity fails in this case though one hundred observations are available. But the observed value of E_2 of nearly ±5 kilometers, determined from these 100 observations, indicates that the velocity is variable. All of the results are well satisfied with a period of 80 days, though the individual observations depart strongly from the velocity curve, as we should expect, from the nature of the spectrum considered. Seven normal places were formed which satisfied roughly a smooth curve corresponding to the above period, with a range of about sixteen kilometers. The velocity of the center of mass is approximately −37 kilometers. The observations already at hand are regarded as being sufficient to warrant a least squares solution, and the results are to be considered in a later paper.

α LYRÆ

R. A. $18^h\ 33^m.6$; Decl. $+38°\ 41'$

The spectrum of α Lyræ belongs to Class Ao, and contains lines of hydrogen, calcium, titanium, iron, and magnesium. The hydrogen lines are broad, while the fainter metallic lines in general are sharp and well defined. Of the early type spectra considered in this paper, the spectrum of α Lyræ, on account of the good quality of its lines, is capable of yielding the most reliable radial velocity.

TABLE 8

PLATE	GR. M. T.	VEL.	p.	P. E.	n.	EXP.	EM.	S.
543	1912 May 14.792	−12.2	13	±1.87	9	2	LS	3
613†	30.711	−11.7	26	0.92	13	1	LS	1
631	31.762	−17.1	24	1.78	10	1	LS	3
702	June 8.792	−11.3	13	1.84	10	1	23	4
746*	19.726	−13.2	20	1.00	10	3	LS	1
803	July 2.750	−14.5	13	1.53	8	3	LS	3
880*	17.763	−12.9	16	0.76	10	2	LS	3
908	26.749	−15.7	23	1.24	12	1	LS	2
964*	Oct. 11.680	−19.0	22	1.05	11	2	LS	2
1012†	Aug. 22.701	−15.0	12	1.72	10	2	LS	2.5
1047	Sept. 4.586	−18.1	15	1.36	10	1	23	3
1056*	6.625	−17.7	16	1.31	8	1	23	3
1103‡	26.625	−19.0	11	1.47	10	3	LS	2.5
1204	Oct. 7.660	−14.4	12	2.10	9	1	23	2
1408‡	Nov. 7.524	−15.0	15	1.51	10	2	LS	3
2085	1913 July 2.750	−17.5	14	0.84	10	1	23	2
2092†	5.702	−14.8	14	1.67	10	1	23	1.5
2093	5.705	−11.8	13	1.77	11	1	23	1.5
2101	7.762	−16.8	17	0.92	10	1	23	2.5
2111	20.629	−14.7	17	±1.04	11	1	LS	1

*Hadley, †Curtiss, ‡Hess.

Average weighted velocity = −15.2 km. ±0.38 km.
Velocity range = 7.7 km.
E_1 = ±1.36 km., E = ±1.67 km., E_2 = ±0.97 km.

	PUBLISHED VELOCITIES	MELLOR — PUBL. VEOC.
Vogel	−14.0 km.	−1.2 km.
Scheiner	−16.5	+1.3
Lick Observatory	−13.8	−1.4

On account of the small velocity range, together with the correspondingly small value of E_2, and in consideration of the character of the small difference between the Ann Arbor results and those obtained by other observers, the velocity of α Lyræ is regarded as being constant.

α AQUILÆ

R. A. $19^h\ 45^m.9$; Decl. +8° 36′

The spectrum of α Aquilæ, classified as A5, is very difficult of measurement, since it contains lines which are very diffuse and ill defined. The spectrum of this star resembles very closely the spectra of β and δ Leonis. Probably the peculiarities in the spectral lines of these three stars are attributable to the same general causes.

Professor Vogel attributed the marked broadening of the lines to conditions of temperature and pressure in the atmosphere of the star, and he states, "the hydrogen lines are much broadened as a result of the conditions of temperature and pressure in the star's atmosphere, and they are rendered a little more diffuse by the star's rotation. In addition to the hydrogen lines, numerous metallic lines are present, and the composition of the atmosphere of the star approaches that of stars of the second spectral class. All of the lines are, however, broadened in consequence of a strong rotation, so that close lines form diffuse bands, while the stronger isolated lines appear diffuse."

The spectrum of Altair in quality is much poorer than that given by any other star considered in this paper, but nevertheless several of the lines appear double, due to central reversal, as in the cases of β and δ Leonis. The separation of the doubled lines resolved was observed, and plotted with respect to wave-length. The equation of the line expressing the variation of separation of components with wave-length is

$$\Delta\lambda = 0.001456\ (\lambda - 3040)$$

where $\Delta\lambda$ is given in angstroms. The slope of the line given above is slightly less than that found in the case of β Leonis. Apparently the factors previously mentioned, if they determine the separation of the components in the spectra of both these stars, are nearly the same in their totality in the two cases. The spectral lines in α Aquilæ are much more diffuse than those in δ Leonis, which again are inferior to those in the spectrum of β Leonis.

Only five lines of known wave-length were available for determining the radial velocity of this star, on which the data in the following table depend.

M. Deslandres secured twenty-nine observations of this star between the years 1892 and 1895 inclusive and obtained a mean velocity of − 18.9 kilometers, which appears not in agreement with the results given below. In all probability the divergent results of Deslandres do not establish velocity variation. The writer's value of E_2 happens to be imaginary, which gives no evidence that the velocity of this star is variable.

TABLE 9

PLATE	GR. M. T.	VEL.	p.	P. E.	n.	EXP.	EM.	S.
46	1911 June 27.889	−27.7	7	± 9.66	4	5	LS	2
47	27.899	−31.6	3	9.83	3	7	LS	2
52	28.863	−30.6	11	4.31	5	5	LS	2
53	28.868	30.0	7	13.18	4	6	LS	2
58	29.672	24.9	10	12.52	5	3	LS	3
59	29.681	−30.7	5	5.39	5	2	LS	3
64	30.785	−21.5	10	8.38	4	3.5	LS	2
65	30.791	−47.5	10	3.91	5	4	LS	2
71	July 1.683	−32.2	8	5.98	5	4	LS	3
72	1.689	−46.2	4	10.31	4	8	LS	3
78	4.704	−24.2	8	10.31	4	4	LS	2
79	4.710	−31.9	7	9.11	4	8	LS	2
85	5.713	−28.6	4	13.27	3	5	LS	2
86	5.719	−37.9	9	4.21	4	9	LS	2
93	7.763	−23.5	11	7.23	4	4	LS	2
94	7.769	−10.8	8	3.72	4	7	LS	2
100	8.756	−32.2	5	13.52	4	4	LS	2
101	8.761	−32.3	9	± 3.69	4	8	LS	1

All plates by Curtiss.
Average weighted velocity (known) = −28.9 km. ±1.3 km.
Velocity range = 35.4 km.
$E_1 = \pm 6.3$ km., $E = \pm 5.84$ km., $E_2 = \pm 2.4\sqrt{-1}$ km.

PUBLISHED VELOCITIES		MELLOR — PUBL. VELOC.
Vogel	−39.7 km.	+10.8 km.
Scheiner	−34.0	+ 5.1
Lick Observatory	−33.0	+ 4.1
Vogel (29 obs. 1896–97)	−32.9	+ 4.0

DETAILED MEASURES AND REDUCTIONS OF THE LATE TYPE STARS F5 to Mb INCLUSIVE

The remaining sixteen stars in this list, those ranging in spectral type from F5 to Mb inclusive, were reduced in accordance with the so-called zero standard method proposed by Professor R. H. Curtiss. As stated elsewhere this method involves direct comparison between the velocities of two sources, one of which has a known and the other an unknown velocity, the same spectral lines being used in both cases. The moon when nearly in full phase, photographed on two different occasions, was selected as the standard source. The measurements of numerous stellar and comparison lines on each of five moon plates, when reduced to one dispersion, formed a fundamental velocity table which corresponded to a negative displacement of one quarter of a kilometer, the average relative radial velocity of the moon and the earth for the five plates. Since the radial velocities were determined to a tenth of a kilometer this correction was applied to all star reductions. Corrections due to the curvature of spectral lines need not be taken into account in connection with this method of reduction, since a constant slit length was used in making all spectrograms.

Fifty stellar and twenty-nine comparison lines, which constitute the fundamental table, were selected on the basis of their intensity, sharpness, and presence in the spectra of the stars under observation, and the measures upon ten plates of each star were regarded as sufficient for the determination of reliable radial velocity, except in the case of β Cassiopeiæ, for which it was decided to increase the number of plates from ten to fifteen, because the character of its spectrum is such that the accuracy of velocities from individual plates is inferior to that for the other stars of this group.

Of the five plates of the moon two were taken on August 15, and the remaining three on October 13, 1913. The density of the spectrograms is about the same for both sets. The final velocity results obtained from these plates are given in the following table.

The mean residual, observed minus computed velocity, is — 0.12 km. The residuals show at a glance the degree of accuracy which may be obtained by the measurement of a large number of lines in spectra of this type.

In connection with each star, considered in order of right ascension, a table is constructed, giving data for each plate. Columns one, two, and three contain, respectively, the serial plate number, the Greenwich mean time of mid-exposure, and the radial velocity; column four the total weight; column five the probable error for each plate derived from the residuals for the lines with the approximate formula; column six the number of lines used; columns seven and eight the length of exposure time in minutes and the seeing.

TABLE 10

DATE: 1913	AUGUST 15		OCTOBER 13		
PLATE NUMBER	2193	2194	2387	2388	2389
	km.	km.	km.	km.	km.
Observed average displacement	−0.07	+0.38	−0.11	−0.48	+0.22
Correction due to moon's velocity	−0.25	−0.25	−0.25	−0.25	−0.25
Diurnal correction	−0.20	−0.22	−0.04	−0.04	−0.04
Observed velocity	−0.52	−0.09	−0.40	−0.77	−0.07
Computed velocity	−0.19	−0.17	−0.30	−0.30	−0.30
Observed — Computed	−0.33	+0.08	−0.10	−0.47	+0.23

β CASSIOPEIÆ

R. A. $0^h\ 3^m.8$; Decl. $+58°\ 36'$

The spectrum of β Cassiopeiæ is classified as F5, and in many ways resembles that of the sun, although the solar lines are fainter and less numerous than in the solar spectrum. Since the lines in this star are not so well defined as usual in spectra of this type, a total of fifteen plates was used.

Since E_2 is rather large in comparison with the average value of ± 0.9 km., obtained for the solar type stars of the brightness of β Cassiopeiæ, the velocity of this star is thought to be variable. Although the results available at the present time are limited, a velocity curve of small eccentricity with a period of about twenty-seven days is tentatively suggested.

TABLE 11

PLATE	GR. M. T.	VEL.	p.	P. E.	n.	EXP.	S.
1090	1912 Sept. 22.776	+ 7.3	90	±0.83	35	35	1
1091	22.815	+ 6.1	90	0.96	37	35	1
1149	Oct. 2.766	+ 3.6	106	0.79	39	10	4
1150	2.774	+ 7.2	116	0.82	36	10	4
1172	4.724	+10.2	70	1.21	32	8	5
1212	7.769	+14.5	98	0.65	37	7	3
1213	7.774	+14.4	103	0.94	34	7	3
1277	16.738	+ 7.9	118	1.03	34	6	2.5
1278	16.742	+ 9.0	90	0.93	35	5	2.5
1373	27.764	+ 7.0	67	0.87	26	10	2.5
1374	27.772	+ 9.5	75	0.81	31	10	2
1382*	29.700	+ 9.4	70	0.88	29	5	1.5
1591	1913 Jan. 28.616	+ 4.9	79	0.81	29	20	1.5
1592	28.622	+ 7.9	89	0.79	31	12	1.5
1593	28.633	+ 5.9	112	±1.14	36	12	1.5

*Crump and Hess.

Average weighted velocity = + 8.3 km. ±0.57 km.
Velocity range = 10.9 km.
$E_1 = \pm 0.89$ km., $E = \pm 2.12$ km., $E_2 = \pm 2.04$ km.

PUBLISHED VELOCITIES		MELLOR — PUBL. VELOC.
Vogel	+12.8 km.	−4.5 km.
Scheiner	+ 1.3	+7.0
Lick Observatory	+ 9.0	−0.7

α CASSIOPEIÆ

R. A. $0^h\ 34^m.8$; Decl. $+55°\ 59'$

The lines in the spectrum of α Cassiopeiæ appear sharper and more clearly defined than in any of the other Class Ko spectra measured. The value of E_2 is larger than one would expect to find in connection with results obtained from spectrograms of such good quality. Although the velocity range is small, the results tend to show that the velocity is variable. Before a final conclusion can be drawn as to its variability, however, more plates should be taken covering a longer period.

TABLE 12

PLATE	GR. M. T.	VEL.	p.	P. E.	n.	EXP.	S.
1173	1912 Oct. 4.757	− 7.9	103	±0.30	43	5	5
1174	4.762	− 5.2	92	0.31	38	5	5
1215	7.789	− 0.7	62	0.61	31	6	2.5
1375	27.781	− 9.0	87	0.40	35	8	2.5
1376	27.788	− 9.2	86	0.43	38	10	2
1384*	29.721	− 4.6	92	0.33	37	8	
1459	Nov. 15.659	− 4.9	101	0.36	39	7	2
1460	15.665	− 3.8	91	0.29	38	7	2
1598	1913 Feb. 7.544	− 4.1	96	0.41	41	12	2
1599	7.554	− 7.7	96	±0.46	40	12	2

*Hess and Crump.

Average weighted velocity = −5.9 km. ±0.56 km.
Velocity range = 8.5 km.
$E_1 = \pm 0.38$ km., $E = \pm 1.69$ km., $E_2 = \pm 1.65$ km.

PUBLISHED VELOCITIES			MELLOR — PUBL. VELOC.
Vogel	−14.9 km.		+9.0 km.
Scheiner	−15.6	(4)	+9.7
Lick Observatory	− 3.8		−2.1
Lord	− 0.4	(5)	−5.5
Maag	− 2.6	(5)	−3.3
Zurhellen	− 2.5	(4)	−3.4
Knatek	− 6.3	(1)	+0.4

γ ANDROMEDÆ

R. A. $1^h\ 57^m.8$; Decl. $+41°\ 51'$

The spectrum of γ Andromedæ, a visual double, is classified in the *Harvard Annals* as being K peculiar, showing a composite structure. The spectrum of the brighter component, however, resembles that of α Cassiopeiæ, although in comparison with it the finer lines are not quite so sharp, though well defined. The degree of accordance among the different velocities of the two should be about the same.

The final velocities for this star are in good agreement, the range being less than four kilometers. The value of E_2 is less than fifty per cent of that for α Cassiopeiæ. The fact that the spectrograms of γ Andromedæ yield more consistent results than those of α Cassiopeiæ perhaps can be best explained by assuming a small variation in the radial velocity of the latter.

TABLE 13

PLATE	GR. M. T.	VEL.	p.	P. E.	n.	EXP.	S.
1177	1912 Oct. 4.798	−13.6	99	±0.31	41	5	5
1178	4.803	−14.2	92	0.31	37	5	5
1380	27.835	−10.9	99	0.44	45	10	2
1500	Nov. 22.675	−12.5	92	0.48	38	15	-
1501	22.698	−13.9	97	0.49	35	20	1.5
1512	29.657	−12.7	73	0.50	36	15	3
1513	29.697	−10.6	92	0.43	36	15	3
1612	1913 Feb. 12.580	−13.5	85	0.59	36	15	1.5
1614	17.566	−13.1	94	0.44	39	15	1.5
1615	17.595	−14.5	93	±0.42	38	15	1.5

Average weighted velocity = −12.9 km. ±0.30 km.
Velocity range = 3.9 km.
E_1 = ±0.44 km., E = ±0.89 km., E_2 = ±0.77 km.

PUBLISHED VELOCITIES			MELLOR — PUBL. VELOC.
Vogel	− 7.9 km.		−5.0 km.
Scheiner	−17.8	(3)	+4.9
Lick Observatory	−10.7		−2.2
Maag	− 7.1	(5)	−5.8
Zurhellen	−10.4	(4)	−2.5
Knatek	− 9.9	(1)	−3.0

α ARIETIS

R. A. $2^h\ 1^m.5$; Decl. $+22°\ 59'$

The spectrum of α Arietis is classified as K2, containing numerous and well defined lines. The solar lines resemble those in α Cassiopeiæ, with the exception of slight differences in their intensities. A reproduction of an enlargement of this spectrum is shown in Volume II, Plate G, of these *Publications*.

On account of the magnitude of E_2, which is ±0.75 km. greater than the expected average value for this star were the velocity constant, it is possible that the velocity of this star is slightly variable.

TABLE 14

PLATE	GR. M. T.	VEL.	p.	P. E.	n.	EXP.	S.
1179	1912 Oct. 4.812	−17.2	95	±0.39	41	5	5
1180	4.817	−13.8	100	0.36	42	5	5
1465	Nov. 15.733	−20.2	107	0.29	41	9	3
1466	15.740	−19.4	84	0.44	37	9	3
1502	22.718	−16.7	100	0.43	40	15	2
1514	29.714	−14.3	101	0.51	40	15	3
1515	20.725	−13.1	108	0.39	41	15	3
2307	1913 Sept. 9.834	−14.9	91	0.58	39	8	2
2308	9.850	−13.3	77	0.45	37	8	2
2322	22.842	−12.7	85	±0.32	35	8	2

Average weighted velocity = −15.6 km. ±0.60 km.
Velocity range = 7.5 km.
E_1 = ±0.41 km., E = ±1.80 km, E_2 = ±1.75 km.

	PUBLISHED VELOCITIES		MELLOR — PUBL. VELOC.
Vogel	−14.5 km.		−1.1 km.
Scheiner	−14.9	(5)	−0.7
Lick Observatory	−14.0		−1.6
Lord	−14.0	(2)	−1.6
Maag	−12.5	(5)	−3.1
Frost	−13.5	(3)	−2.1
Adams	−13.9	(4)	−1.7
Newall	−15.8	(11)	+0.2
Slipher	−14.3	(3)	−1.3
Zurhellen	−12.8	(6)	−2.8
Plaskett	−14.9	(4)	−0.7

α PERSEI

R. A. $3^h\ 17^m.2$; Decl. $+49°\ 30'$

The spectrum of α Persei is classified as F5 and resembles that of β Cassiopeiæ, although the solar lines are slightly more intense and are much more clearly defined.

Many spectrograms have been made of this star since 1900, when Newall (*Mon. Not.* Vol. 61, p. 13, 1900) obtained a series of observations from which he concluded that its velocity was variable. He was unable to determine from his observations the precise character of its orbit. His conclusions were, however, that α Persei was moving in an approximately circular orbit in a period of 4.20 days, or in an elliptical orbit of considerable eccentricity with a period of about 16.8 days. The results of Campbell (*Lick Observatory Bulletin*, Vol. 1, p. 23, 1901) did not afford any evidence of variable velocity. From December 13, 1900 to January 9, 1901, Vogel obtained a series of 13 plates and was unable to confirm Newall's results. Later, Goos from 47 observations (*Ast. Nach.*, Vol. 180, p. 55, 1909) derived a period of 290 days, and Knatek (*Ast. Nach.* Vol. 192, p. 18, 1912) a period of 4.09 days. The combined radial velocity results of α Persei were finally studied by J. H. Pitman (*Lick Observatory Bulletin*, Vol. 7, p. 101, 1912-13) and the conclusions drawn from his investigations

TABLE 15

PLATE	GR. M. T.	VEL.	p.	P. E.	n.	EXP.	S.
2472	1913 Dec. 8.751	− 6.4	109	±0.44	38	5	2.5
2473	8.767	− 8.1	89	0.50	37	5	2 5
2503	16.719	− 4.0	93	0.44	40	3	2.5
2504	16.728	− 5.9	82	0.44	36	1.5	2.5
2533	1914 Jan. 13.617	− 7.0	63	0.58	34	8	1 5
2534	13.624	− 5.4	89	0.65	32	8	2
2542	17.638	−10.0	86	0.64	37	4	2 5
2610	Mar. 9.593	− 5.9	50	0.70	29	4	3
2617	11.560	− 2.9	117	0.46	38	3	2
2618	11.572	− 3.7	109	±0.53	39	2.5	2

Average weighted velocity = −5.7 km. ±0.50 km.
Velocity range = 7.1 km.
E_1 = ±0.53 km., E = ±1.51 km., E_2 = ±1.41 km.

	PUBLISHED VELOCITIES		MELLOR — PUBL. VELOC.
Vogel	−10.8 km.		+5.1 km.
Scheiner	− 9.8		+4.1
Vogel	− 3.2 (1900–01)	(3)	−2.5
Lick Observatory	− 2.2		−3.5
Maag	+ 0.6	(5)	−6.3
Frost	− 2.3	(3)	−3.4
Adams	− 2.0	(3)	−3.7
Belopolsky	− 2.9	(8)	−2.8
Newall	− 1.0	(33)	−4.7
Slipher	− 2.5	(5)	−3.2
Zurhellen	− 2.3	(6)	−3.4
Goos	− 1.7	(47)	−4.0
Knatek	− 3.4	(54)	−2.3
Plaskett	− 2.1	(3)	−3.6

were that its radial velocity was either constant, or only slightly variable in a period still undetermined.

The value of E_2 and the range from the Ann Arbor velocities were not regarded as indicating variability. The frequency curve of this star was studied, using seventy-four observations, including those of Frost, Adams, Küstner, Goos, and the Lick observations. The resulting curve resembled very closely the well known error curve. A frequency curve drawn through Goos' observations alone also shows a similarity to the above curve, although it is slightly unsymmetrical.

α TAURI

R. A. $4^h\ 30^m.2$; Decl. $+16°\ 19'$

The spectrum of α Tauri is classified in the *Harvard Annals* as K5, and is regarded as typical of this class. The solar lines are well defined.

The value of E_2, ±1.47 km., and the velocity range do not indicate that the velocity of α Tauri is variable. Though the Ann Arbor velocities differ from those of other observers by slightly more than the average amount, this may be explained by the fact that the violet region in this spectrum is relatively faint, from λ 3987 to λ 4092, so that the region of spectrum employed differs slightly from that on which the other velocities by the writer are based. Though no definite conclusion is possible, the Ann Arbor velocities of 1912 seem to suggest a velocity curve of very small amplitude, represented by a period of about fifty-three days. The observation of 1913 when reduced to this epoch falls upon the curve.

TABLE 16

PLATE	GR. M. T.	VEL.	p.	P. E.	n.	EXP.	S.
1162	1912 Oct. 2.906	+48.3	48	±0.90	25	10	4
1163	2.921	+51.0	76	0.67	33	10	4
1182	4.890	+51.9	99	0.58	39	7	4.5
1387*	29.760	+54.0	92	0.39	37	4	
1469	Nov. 15.794	+47.2	93	0.47	38	5	3
1470	15.800	+47.3	85	0.56	36	5	3
1518	29.783	+51.5	83	0.83	32	3	3
1519	29.788	+53.4	86	0.70	32	3	3
2323	1913 Sept. 22.856	+50.9	94	0.59	35	10	2
2324	22.872	+52.0	96	±0.60	34	10	2

*Crump and Hess.

Average weighted velocity = +50.9 km. ±0.53 km.
Velocity range = 6.8 km.
E_1 = ±0.62 km., E = ±1.60 km., E_2 = ±1.47 km.

PUBLISHED VELOCITIES			MELLOR — PUBL. VELOC.
Vogel	+47.6 km.		+3.3 km.
Scheiner	+49.4		+1.5
Lick Observatory	+55.1		−4.2
Adams	+56.1		−5.2
Maag	+55.9	(5)	−5.0
Zurhellen	+56.1	(7)	−5.2

α CANIS MINORIS

R. A. $7^h\ 34^m.1$; Decl. $+5°\ 29'$

Alpha Canis Minoris is classified as F5 and was included in this list since its variation in velocity is very slight, and therefore may be regarded as being practically constant so far as the results of single prism observations are concerned. Owing to the variable proper motion of Procyon, the existence of a physical companion was long ago suspected. In 1861, Auwers computed the position of the hypothetical companion with reference to the primary star, and deduced a period of nearly 40 years for it. The existence of such a companion, however, was not verified until 1896, when Professor Schæberle discovered it visually and made the first measures of it.

This star has been observed at the Lick Observatory, with the Mills spectrograph, during a number of years. It is interesting to note that the Lick observations appear to show a secondary variation of radial velocity, with a period of about seven years, and a double amplitude of about 1.5 kms. per second.

The Ann Arbor velocities are in good agreement with those obtained at Lick Observatory and by Zurhellen. E_2 is about one-tenth of a kilometer greater than the expected average value.

TABLE 17

PLATE	GR. M. T.	VEL.	p.	P. E.	n.	EXP.	S.
404*	1912 Mar. 29.672	+ 1.2	89	±0.54	33	5	1.5
440	Apr. 10.583	− 2.7	111	0.49	39	5	4
441	10.587	− 2.5	104	0.61	34	5	4
1568	1913 Jan. 8.815	− 3.3	103	0.48	34	4	2.5
1586	24.736	− 3.8	114	0.50	37	2	2
1645	Apr. 1.592	− 6.8	95	0.50	34	2	2
1688	14.571	− 3.5	117	0.40	40	2	2
1689	14.624	− 5.6	128	0.40	39	2	1.5
1768	29.561	− 6.6	83	0.47	35	0.8	2
1769	29.571	− 4.3	103	±0.42	34	0.5	2

*Hadley.

Average weighted velocity = −3.8 km. ±0.53 km.
Velocity range = 8.0 km.
E_1 = ±0.48 km., E = ±1.58 km., E_2 = ±1.51 km.

	PUBLISHED VELOCITIES		MELLOR — PUBL. VELOC.
Vogel	− 7.9 km.		+4.1 km.
Scheiner	−10.5	(5)	+6.7
Lick Observatory	− 3.5		−0.3
Zurhellen	− 3.6	(7)	−0.2

β GEMINORUM

R. A. $7^h\ 39^m.2$; Decl. $+28°\ 16'$

The spectrum of β Geminorum is classified as Ko, resembling that of γ Andromedæ, and containing numerous sharp and well defined lines.

The range in velocity is smaller than the expected average for this star. The value of E_2 is relatively small, indicating no variation.

TABLE 18

PLATE	GR. M. T.	VEL.	p.	P. E.	n.	EXP.	S.
310	1912 Mar. 10.624	+ 3.2	85	±0.52	36	4	3
311	10.631	− 0.2	86	0.51	37	4	3
312	10.656	+ 4.9	80	0.57	39	2.5	3
325	12.622	+ 2.7	82	0.65	36	4	2
326	12.633	+ 2.3	79	0.45	36	4	2
1570	1913 Jan. 8.842	+ 3.3	95	0.44	40	7	2.5
1571	8.862	+ 1.6	106	0.82	43	7	2.5
1589	24.778	+ 1.1	102	0.92	41	4	2.5
1647	Apr. 1.625	− 0.1	103	0.39	40	2.5	2
1690	14.595	+ 1.5	116	±0.44	43	5	1.5

Average weighted velocity = +1.9 km. ±0.38 km.
Velocity range = 5.0 km.
E_1 = ±0.57 km., E = ±1.04 km., E_2 = ±0.87 km.

PUBLISHED VELOCITIES			MELLOR — PUBL. VELOC.
Vogel	+1.9 km.		0.0 km.
Scheiner	+0.4		+1.5
Lick Observatory	+3.9		−2.0
Adams	+3.7	(3)	−1.8
Frost	+3.2	(3)	−1.3
Belopolsky	+3.4	(9)	−1.5
Maag	+5.3	(5)	−3.4
Newall	+2.0	(6)	−0.1
Slipher	+3.3	(3)	−1.4
Zurhellen	+4.8	(10)	−2.9
Plaskett	+4.1	(3)	−2.2

γ LEONIS

R. A. $10^h\ 14^m.5$; Decl. $+20°\ 21'$

Gamma Leonis is a visual double star, the magnitudes of its components being 2.6 and 3.8. In the *Harvard Annals* the spectrum of each component is classified as Ko. The spectrum of the brighter component resembles that of γ Andromedæ, although the solar lines in the blue region are not so sharply defined. Belopolsky (*Astr. Nach.* Vol. 147, p. 92, 1898) investigated the velocity of the system and found the relative velocity of the two components to be 2.2 kms. The Lick Observatory observations differ only 0.1 km. for the two components.

A slight variation in the velocity of this star is suspected.

TABLE 19

PLATE	GR. M. T.	VEL.	p.	P. E.	n.	EXP.	S.
2563	1914 Feb. 4.822	−37.2	100	±0.66	41	20	2.5
2601	24.724	−37.2	126	0.41	46	20	2.5
2602	24.763	−34.0	108	0.47	43	20	2.5
2605	Mar. 2.720	−34.0	97	0.36	40	20	2.5
2606	2.750	−36.5	101	0.36	42	15	2.5
2613	9.713	−39.5	99	0.58	40	10	3
2614	9.732	−38.7	81	0.58	39	5	3
2643	16.665	−41.2	94	0.51	41	15	2
2691	Apr. 13.613	−33.1	114	0.47	43	14	2
2692	13.633	−35.7	119	±0.52	46	14	2

Average weighted velocity = −36.6 km. ±0.57 km.
Velocity range = 8.1 km.
E_1 = ±0.49 km., E = ±1.72 km., E_2 = ±1.65 km.

PUBLISHED VELOCITIES			MELLOR — PUBL. VELOC.
Vogel	−36.5 km.		−0.1 km.
Scheiner	−40.5	(4)	+3.9
Lick Observatory	−35.0*		−1.6
Maag	−32.3	(5)	−4.3
Küstner and Zurhellen	−34.8	(6)	−1.8

*Estimated velocity of center of visual system.

α BOOTIS

R. A. $14^h\ 11^m.1$; Decl. $+19°\ 42'$

The spectrum of α Bootis is classified as Ko. As compared with those in γ Leonis, the solar lines are slightly better defined.

Comparing the results for the two consecutive years, it will be noted that the velocity appears to vary. The average velocity from six plates obtained in 1912 is − 5.3 km., while that for 1913 from four plates is − 9.4 km. The difference in velocity of 4.1 km. can hardly be due to a change in personal equation since the plates were measured in rapid succession and not in the order in which they were taken. A variation in radial velocity would of course account for such a difference, and groups of plates taken with higher dispersion at yearly intervals might seem desirable. However, it is brought out later in this paper that velocities determined from spectrograms of very short exposure are liable to error. Since six of the plates of α Bootis were made with exposures of only two minutes or less, the agreement among the velocities obtained for this star may be expected to be inferior to the average for fainter stars with similar spectra. The value ±1.57 km. for E_2 is not unexpectedly large for so bright a star.

TABLE 20

PLATE	GR. M. T.	VEL.	p.	P. E.	n.	EXP.	S.
464	1912 Apr. 24.748	− 4.3	188	±0.50	40	2	2.5
465	24.754	− 5.7	100	0.48	42	2	2.5
480	26.803	− 5.5	184	0.58	41	2	3
954	Aug. 4.647	− 3.7	109	0.36	43	10	2
955*	4.656	− 6.4	82	0.54	37	10	2
1096	Sept. 23.543	− 6.0	105	0.48	45	25	1
1673	1913 Apr. 7.826	−10.4	108	0.44	45	1.5	2
1702	14.773	−10.2	87	0.57	37	2	1
1703	14.780	− 9.7	108	0.50	40	2	1
1784	29.754	− 7.4	109	±0.39	44	3	3.5

*Hadley and Mellor.

Average weighted velocity = −7.0 km. ±0.55 km.

Velocity range = 6.7 km.

E_1 = ±0.48 km., E = ±1.64 km., E_2 = ±1.57 km.

PUBLISHED VELOCITIES			MELLOR — PUBL. VELOC.
Vogel	−7.0 km.		0.0 km.
Scheiner	−8.3	(7)	+1.3
Lick Observatory	−3.9		−3.1
Adams	−4.3	(6)	−2.7
Frost	−4.2	(4)	−2.8
Maag	−3.2	(8)	−3.8
Newall	−6.4	(25)	−0.6
Slipher	−4.7	(5)	−2.3
Zurhellen	−3.9	(6)	−3.1
Plaskett	−4.6	(11)	−2.4
Belopolsky	−6.1	(9)	−0.9

ϵ BOOTIS

R. A. $14^h\ 40^m.6$; Decl. $+27°\ 30'$

Epsilon Bootis is a close double, the magnitudes of its components being 2.7 and 5.1. The spectrum of each component is classified as Ko.

The Ann Arbor velocities of this star are in good agreement, E_2 being close to the expected value. Küstner (*Astrophysical Journal*, Vol. 27, p. 313, 1908) obtained a range of 6.4 km. in his final results for ϵ Bootis, and, therefore, suspected that its velocity was variable.

TABLE 21

PLATE	GR. M. T.	VEL.	p.	P. E.	n.	EXP.	S.
466	1912 Apr. 24.794	−15.1	86	±0.50	40	10	2.5
493	30.751	−17.3	87	0.59	38	10	2.5
501*	May 2.759	−17.0	102	0.36	45	15	2
502*	2.772	−20.0	99	0.43	43	15	2
523*	8.806	−17.8	80	0.46	42	15	3
524*	8.822	−18.8	68	0.59	32	18	3
1675	1913 Apr. 7.864	−15.5	105	0.52	40	12	1
1766	28.815	−15.8	104	0.37	41	14	2
1785	29.768	−17.3	102	0.39	42	4	3.5
1786	29.781	−20.2	99	±0.45	40	3	3

*Hadley.

Average weighted velocity = −17.4 km. ±0.40 km.
Velocity range = 5.1 km.
$E_1 = \pm 0.46$ km., $E = \pm 1.21$ km., $E_2 = \pm 1.12$ km.

PUBLISHED VELOCITIES			MELLOR — PUBL. VELOC.
Vogel	−16.8 km.		−0.6 km.
Scheiner	−15.7	(4)	−1.7
Lick Observatory	−16.4		−1.0
Maag	−15.5	(5)	−1.9
Küstner and Zurhellen	−15.0	(6)	−2.4

β URSÆ MINORIS

R. A. $14^h\ 51^m.0$; Decl. $+74°\ 34'$

The spectrum of β Ursæ Minoris is classified as K5, and resembles that of α Tauri. The solar lines are well defined and exceedingly sharp.

The velocity of β Ursæ Minoris is suspected of being variable, since the value of E_2 is about 0.8 km. larger than the expected average. The velocities given in the table seem to show periodic variations in 1912, though this may be accidental. The plates made on the same night are in good agreement. Not enough observational data are at hand to obtain an idea as to its period.

TABLE 22

PLATE	GR. M. T.	VEL.	p.	P. E.	n.	EXP.	S.
500*	1912 May 2.736	+12.8	82	±0.53	35	10	2
521*	8.755	+15.2	82	0.66	33	10	3
527†	9.754	+17.2	106	0.58	40	14	2
528†	9.767	+19.0	99	0.36	42	14	2
610†	30.670	+21.0	82	0.54	38	11	1
611†	30.686	+20.4	79	0.63	36	12	1
640†	June 2.654	+15.0	67	0.58	33	8	1
641†	2.661	+13.3	64	0.68	31	8	1
1677	1913 Apr. 7.903	+13.8	92	0.49	39	10	0.5
1678	7.912	+15.3	87	±0.52	38	10	0.5

*Hadley, †Curtiss.

Average weighted velocity = +16.4 km. ±0.65 km.

Velocity range = 8.2 km.

$E_1 = \pm 0.55$ km., $E = \pm 1.95$ km., $E_2 = \pm 1.87$ km.

PUBLISHED VELOCITIES		MELLOR — PUBL. VELOC.
Vogel	+14.2 km.	+2.2 km.
Scheiner	+14.2 (6)	+2.2
Lick Observatory	+17.2	−0.8

α SERPENTIS

R. A. $15^h\ 39^m.3$; Decl. $+6°\ 44'$

The spectrum of α Serpentis is classified as Ko, the solar lines being sharp and well defined.

The Ann Arbor velocity of this star differs by 21 km. from the Potsdam values, but agrees well, after considering systematic differences, with the results obtained at the Lick Observatory. In the *Publikationen des Astrophysikalischen Observatoriums zu Potsdam*, Vol. VII, p. 56, 1892, Vogel states that the spectrum of α Serpentis, on account of its faintness, is unsuitable for measurement. This, with the method of measurement employed at that time, probably accounts for such a difference, since more recent results are accordant. The small value of E_2 indicates that the velocity of this star is constant.

TABLE 23

PLATE	GR. M. T.	VEL.	p.	P. E.	n.	EXP.	S.
648*	1912 June 2.739	+ 0.7	86	±0.52	37	12	1
649*	2.749	+ 2.1	93	0.38	39	14	1
1789	1913 Apr. 29.814	+ 2.5	106	0.58	41	4	2.5
1790	29.826	+ 1.4	87	0.66	36	3	2.5
2021	June 15.723	+ 0.2	73	0.72	32	10	2
2022	15.750	− 1.0	63	0.69	31	12	2
2084	July 2.722	+ 0.6	68	0.76	29	25	1.5
2104	9.707	+ 2.4	94	0.54	38	20	2
2157	Aug. 1.629	+ 3.0	109	0.39	41	18	2
2158	1.651	− 1.0	84	±0.74	34	10	1.5

*Curtiss.

Average weighted velocity = +1.3 km. ±0.32 km.
Velocity range = 4.0 km.
E_1 = ±0.59 km., E = ±0.95 km., E_2 = ±0.74 km.

PUBLISHED VELOCITIES			MELLOR — PUBL. VELOC.
Vogel	+22.3 km.	(1)	−21.0 km.
Maag	+ 5.9	(5)	− 4.6
Lick Observatory	+ 3.4		− 2.1

γ CYGNI

R. A. $20^h\ 18^m.6$; Decl. $+39°\ 56'$

The spectrum of γ Cygni is classified as F8p, containing many narrow, sharp and well defined lines. The intensities of certain lines differ considerably from those in the typical star.

The range for this star is very small. There seems to be no evidence of variability in the Ann Arbor observations alone.

TABLE 24

PLATE	GR. M. T.	VEL.	p.	P. E.	n.	EXP.	S.
654†	1912 June 2.858	− 9.6	126	±0.29	41	10	2
729†	10.795	−10.3	99	0.33	40	12	1.5
744*	12.842	−10.5	121	0.49	39	16	2
882[1]	July 17.797	−10.4	122	0.44	39	5	3
883[1]	17.802	−11.0	130	0.31	41	6	3
895	18.780	− 8.5	130	0.41	40	6	2
970[2]	Aug. 11.801	− 8.9	143	0.44	42	6	3
1050*	Sept. 4.698	− 7.9	138	0.53	40	6	2
1935	1913 June 2.803	−10.2	140	0.28	42	5	2.5
1936	2.808	− 9.4	136	±0.39	42	5	2.5

*Hadley, †Curtiss, [1]Hadley and Hess, [2]Hadley and Crump.
Average weighted velocity = −9.6 km. ±0.22 km.
Velocity range = 3.1 km.
$E_1 = \pm 0.39$ km., $E = \pm 0.67$ km., $E_2 = \pm 0.54$ km.

PUBLISHED VELOCITIES			MELLOR — PUBL. VELOC.
Vogel	−5.8 km.		−3.8 km.
Scheiner	−6.9	(4)	−2.7
Lick Observatory	−5.1		−4.5
Maag	−4.1	(5)	−5.5
Knatek	−9.4	(2)	−0.2

ϵ PEGASI

R. A. $21^h\ 39^m.3$; Decl. $+9°\ 25'$

The spectrum of ϵ Pegasi is classified as Ko.

There is no evidence of variability in the velocity of this star.

TABLE 25

PLATE	GR. M. T.	VEL.	p.	P. E.	n.	EXP.	S.
1166	1912 Oct. 4.622	+ 1.7	105	±0.50	41	10	4.5
1167	4.635	+ 0.2	103	0.33	39	8	4.5
1394	30.569	+ 1.6	103	0.47	39	15	2
1395	30.581	+ 1.1	87	0.61	36	15	2
1400	Nov. 1.642	+ 3.0	93	0.46	37	15	2
1561	Dec. 22.477	+ 2.3	103	0.44	41	15	2.5
1562	22.505	+ 2.1	95	0.38	38	15	2.5
1563	22.517	+ 1.1	106	0.40	43	15	2.5
2166	1913 Aug. 1.847	+ 4.2	79	0.70	32	12	2.5
2228	22.813	+ 4.7	102	±0.44	39	15	2

Average weighted velocity = +2.2 km. ±0.31 km.
Velocity range = 4.5 km.
E_1 = ±0.47 km., E = ±0.94 km., E_2 = ±0.81 km.

PUBLISHED VELOCITIES			MELLOR — PUBL. VELOC.
Vogel	+7.3 km.		−5.1 km.
Scheiner	+8.7	(3)	−6.5
Lick Observatory	+5.0		−2.8
Adams	+6.2	(3)	−4.0
Frost	+6.2	(3)	−4.0
Belopolsky	+6.0	(7)	−3.8
Maag	+6.1	(5)	−3.9
Newall	+3.3	(3)	−1.1
Slipher	+6.1	(4)	−3.9

β PEGASI

R. A. $22^h\ 58^m.9$; Decl. $+27°\ 32'$

The spectrum of β Pegasi is classified as Mb. The absorption bands of titanium oxide, usually found in this type of spectrum, are distinctly seen and show abrupt changes in intensity on the less refrangible side.

On account of the large value of E_2, which is nearly three kilometers, the velocity of this star is considered as being variable. The Ann Arbor velocities suggest a period of about 52 days, with a rather large eccentricity.

TABLE 26

PLATE	GR. M. T.	VEL.	p.	P. E.	n.	EXP.	S.
1168	1912 Oct. 4.653	+ 3.0	87	±0.64	29	10	4.5
1169	4.667	+ 3.0	119	0.72	37	10	4.5
1209	7.719	+ 7.3	95	0.88	29	10	2
1342	25.689	+12.9	109	0.74	37	8	3
1343	25.706	+13.5	114	0.69	33	8	3
1369	27.706	+13.2	98	0.69	30	12	3
1370	27.715	+10.4	112	0.71	33	13	2
1396	30.594	+ 3.2	112	0.82	32	11	2
1397	30.603	+ 6.7	117	0.66	34	11	2
1455	Nov. 15.601	+ 2.2	115	±0.72	35	8	2

Average weighted velocity = + 7.5 km. ±1.02 km.
Velocity range = 11.3 km.
E_1 = ±0.73 km., E = ±3.07 km., E_2 = ±2.98 km.

PUBLISHED VELOCITIES		MELLOR — PUBL. VELOC.
Vogel	+6.7 km.	+0.8 km.
Lick Observatory	+8.4	−0.9

RESUMÉ OF THE FINAL RESULTS

The two following tables contain a summary of the Ann Arbor velocities and probable errors for the stars considered, with the corresponding differences between the writer's final results and those of other observers. The final mean velocities from the Ann Arbor observations with the corresponding probable errors are given in columns three and four of Tables 27 and 28. The numbers in parentheses indicate the number of plates entering into the mean for the observer whose result is compared with the writer's, except in the case of the values by Vogel and Scheiner, for which weights are used. The results are grouped according to spectral classes.

TABLE 27

SUMMARY OF VELOCITIES AND SYSTEMATIC DIFFERENCES FOR STARS OF CLASSES Bo TO A5

STAR	SPECTRUM	MELLOR	PROBABLE ERROR	MELLOR — VOGEL AND SCHEINER	MELLOR — LICK	MELLOR — FROST	MELLOR — ADAMS
		km.	km.	km.	km.	km.	km.
ζ Orionis	Bo	+19.3	±1.14	+ 4.5 (3)	+1.8	−3.4 (2)	+2.8 (5)
η Ursæ Majoris	B3	+ 9.5	1.5	−35.7	+15.5 (1)		
β Tauri	B8	+ 4.6	0.65	− 3.4 (3)	− 6.4		
α Leonis	B8	+ 1.2	1.2	+10.3 (4)			
γ Ursæ Majoris	Ao	−13.4	1.2	+13.2 (3)	− 4.4		
α Lyræ	Ao	−15.2	0.38	+ 0.1 (8)	− 1.4		
δ Leonis	A2	−25.0	1.12	− 5.6 (3)	− 7.0		
β Leonis	A2	− 4.4	0.8	+ 7.8 (3)	− 5.7		
α Aquilæ	A5	−28.9	±1.3	+ 8.0 (5)	+ 4.1		

TABLE 28

SUMMARY OF VELOCITIES AND SYSTEMATIC DIFFERENCES FOR STARS OF CLASSES F5 TO Mb

STAR	SPECTRUM	MELLOR	PROBABLE ERROR	MELLOR — VOGEL AND SCHEINER	MELLOR — LICK	MELLOR — ADAMS	MELLOR — FROST	MELLOR — PLASKETT	MELLOR — MAAG	MELLOR — LORD	MELLOR — NEWALL	MELLOR — SLIPHER	MELLOR — KÜSTNER	MELLOR — BELOPOLSKY	MELLOR — KNATEK	MELLOR — GOOS
		km.	km.	km.	km.	km.	km.	km.								
β Cassiopeiæ	F5	+ 8.3	±0.57	+ 3.1 (1)	−4.5											
α Canis Minoris	F5	− 3.8	0.53	+ 5.4 (5)	−0.3								−0.2 (7)			
α Persei	F5	− 5.7	0.50	+ 4.0 (4)	−3.5	−3.7 (3)	−3.4 (3)	−3.6	−6.3 (5)		−4.7 (33)	−3.2 (5)	−3.4 (6)	−2.8 (8)	−2.3 (54)	−4.0 (47)
γ Cygni	F8p	− 9.6	0.22	− 3.2 (4)	−4.5				−5.5 (5)						−0.2 (2)	
α Cassiopeiæ	Ko	− 5.9	0.56	+ 9.4 (4)	−2.1				−3.3 (5)	−5.5 (5)			−3.4 (4)		+0.4 (1)	
β Geminorum	Ko	+ 1.9	0.38	+ 0.7 (4)	−2.0	−1.8 (3)	−1.3 (3)	−2.2	−3.4 (5)		−0.1 (6)	−1.4 (3)	−2.9 (10)	−1.5 (9)		
α Bootis	Ko	− 7.0	0.55	+ 0.7 (7)	−3.1	−2.7 (6)	−2.8 (4)	−2.4	−3.8 (8)		−0.6 (25)	−2.3 (5)	−3.1 (6)	−0.9 (9)		
ε Bootis	Ko	−17.4	0.40	− 1.1 (4)	−1.0				−1.9 (5)				−2.4 (6)			
γ Leonis	Ko	−30.6	0.57	+ 1.9 (4)	−1.6				−4.3 (5)				−1.8 (6)			
ε Pegasi	Ko	+ 2.2	0.31	− 5.8 (3)	−2.8	−4.0 (3)	−4.0 (3)		−3.9 (5)		−1.1 (3)	−3.9 (4)		−3.8 (7)		
α Serpentis	Ko	+ 1.3	0.32	−21.0 (1)	−2.1				−4.6 (5)							
γ Andromedæ	Ko	−12.9	0.30	0.0 (3)	−2.2				−5.8 (5)				−2.5 (4)		−3.0 (1)	
α Arietis	K2	−15.6	0.60	− 0.9 (5)	−1.6	−1.7 (4)	−2.1 (3)	−0.7	−3.1 (5)	−1.6 (2)	−0.2 (11)	−1.3 (3)	−2.8 (6)			
α Tauri	K5	+50.9	0.53	+ 2.4 (6)	−4.2	−5.2 (3)			−5.0 (5)				−5.2 (7)			
β Ursæ Minoris	K5	+16.4	0.65	+ 2.2 (6)	−0.8											
β Pegasi	Mb	+ 7.5	±1.02	+ 0.8 (1)	−0.9											

SYSTEMATIC DIFFERENCES

The differences, (Mellor — other observers), given in Tables 27 and 28, are due chiefly to relative systematic errors in the velocity determinations of the observers concerned. The means in Table 29 bring out the relative systematic errors of these observers for different spectral classes and for the mean of all classes. More particularly, for the writer's purpose, they bring out the systematic errors in his own velocities and those of Vogel and Scheiner, referred to the results of twelve other observers. The (negative) quantities in the means in the last row of Table 29 must be subtracted from each of the writer's velocities to reduce them to the average of the other observers. The variations in the writer's systematic error from class to class, as indicated by these quantities, may be real, but it is significant that the stronger means for any spectral class are the ones which accord well with the final mean for all classes. Probably the final mean systematic correction of +2.8 can be applied safely to all my velocities in all spectral classes.

Since it is important to know whether the large systematic correction brought out by the writer's measures is due to personal equation or to instrumental conditions, the data in this connection furnished by the velocity determinations of other observers with the same spectrograph have been collected in Table 30. Of the eight observers whose velocities, obtained with the equipment of this Observatory, are here compared with the results of others, four have negative systematic errors and four have positive ones. The grand mean for all eight observers is — 0.01 km., which indicates that the instrumental sources of systematic error are extremely small in the Ann Arbor spectrographic equipment. The writer's systematic error is not

TABLE 29

SYSTEMATIC DIFFERENCES (MELLOR — OTHER OBSERVERS) FOR SPECTRAL CLASSES

OBSERVERS	Bo – B8	Ao – A5	F5 – F8	Ko – K2	K5	MEANS
	km.	km.	km.	km.	km.	km.
Vogel and Scheiner	+3.8 (3)	+4.7 (5)	+0.7 (2)	+0.8 (9)	+2.4	+2.4
Lick	−2.3 (2)	−2.9 (5)	−4.0 (2)	−2.1 (9)	−4.2	−2.7
Adams	+2.8 (1)		−3.7 (1)	−2.5 (4)	−5.2	−3.0
Frost	−3.4 (1)		−3.4 (1)	−2.6 (4)		−2.8
Plaskett			−3.6 (1)	−1.8 (3)		−2.2
Maag			−5.9 (2)	−3.8 (9)	−5.0	−4.2
Lord				−4.2 (2)		−4.2
Newall			−4.7 (1)	−0.4 (4)		−1.4
Slipher			−3.2 (1)	−2.3 (4)		−2.4
Küstner			−3.4 (1)	−2.7 (7)	−5.2	−3.1
Belopolsky			−2.8 (1)	−2.0 (3)		−2.3
Knatek			−1.3 (2)	−1.3 (2)		−1.3
Goos			−4.0 (1)			−4.0
Means	−1.6	−2.9	−3.6	−2.3	−4.9	−2.8

NOTES. 1. Bo — B8 does not include η Ursæ Majoris. 2. F5 — F8 does not include β Cassiopeiæ and α Canis Minoris. 3. Ko does not include α Serpentis for Vogel and Scheiner. 4. K5 does not include β Ursæ Minoris. 5. Final means, by Classes, do not include values for Vogel and Scheiner.

exceptionally large considering the dispersion employed. Cases of larger errors of this kind are known. But it is extraordinary that this error should persist in the velocities from spectra of types F5 to K2, for in such cases the results depend on differences between plates made with the same apparatus. Apparently after the standard moon plates were measured at the beginning of the program, my technique at the measuring engine was changed, and the change was maintained throughout the rest of the program. velocities extends through the spectral classes, decreasing one or two kilometers perhaps from Class B to Class K.

DIFFERENCES IN WAVE-LENGTH

In the first columns of Tables 31 and 32 are given the laboratory wave-lengths, indentifications, and remarks, for the lines measured in this investigation in stellar spectra of Classes B and A. The difference between the

TABLE 30

SYSTEMATIC RESIDUALS IN THE ANN ARBOR VELOCITY DETERMINATIONS

STAR	ANN ARBOR VELOCITY	NO. OF PLATES	RESIDUAL	COMPARISON
	km.		km.	
γ Cassiopeiæ	− 6.4	70	−1.2	Curtiss — Lick, Potsdam
δ Orionis	+20.1	74	−2.0	Curtiss — Potsdam
ϵ Orionis*	+25.6	30	−0.8	Curtiss — Lick, Yerkes, Potsdam
β Monocerotis	+22.4	11	+0.8	Merrill — Lick
ζ_1Ursæ Majoris	− 7.8	90	+4.0	Hadley — Potsdam
ρ Leonis	+41.1	43	+0.1	Dawson — Lick, Ottawa
α Lyræ	−13.1	20	−0.7	Rossiter — Mellor corrected
α Lyræ	−13.0	20	−0.6	Swift — Mellor corrected
α Lyræ	−12.0	20	+0.4	Halbert — Mellor corrected
Many stars		Many	−2.8	Mellor — Other observers

Table 29 furnishes the following systematic corrections to be applied algebraically to the velocities of Vogel and Scheiner to reduce them to the mean of other observers: for Classes Bo–B8, +5.4 km.; Ao − A5, +7.6 km.; F5 − F8, +4.3 km.; Ko − K5, +3.5 km.; all classes, +5.2 km. In his study of the orbital elements of Algol, Professor Curtiss found a systematic correction of +5.2 km. necessary to reduce the velocities of this star obtained from twelve plates by Vogel and Scheiner to the curve derived from many plates by Belopolsky; and for four Orion stars we have the difference, Frost and Adams — Vogel and Scheiner, +4.1 km. All these results are in close agreement and indicate well that *the early Potsdam velocities are systematically about 5 km. too small algebraically.* The writer's comparisons show that this correction to the Potsdam laboratory wave-length for any given line and that measured in the star, the intensity estimated on the basis of 10, and the sum of the assigned weights, are tabulated under each star. In the last column of each table are given the mean differences of wave-length and their corresponding weights. Of the forty-nine lines measured, only seven are common to both types, hence very little can be said from the data at hand concerning systematic differences in wave-length for these two spectral classes. Except in the case of the Hβ and Hζ lines of hydrogen, the differences in wave-length for lines common to both classes show very little change with spectral type. The larger difference for the Hζ line can easily be attributed to the lack of observations, as well as to the poor quality of the line itself, while results for the Hβ line are less reliable

because of the decreased dispersion in that region of the spectrum.

Table 33 contains similar data for stars with spectra of Classes F5 to Mb inclusive. Here the results are combined into means for groups of stars having similar spectra. Columns 1 and 2 contain the wave-lengths and intensities of the lines determined from the measures of the moon plates for the standard table. Columns 3 to 9 contain the difference in wave-length, and the weight for each line, for each group considered.

Studies of wave-lengths in stellar spectra photographed with three prism spectrographs have revealed changes in wave-length of many lines with spectral type. Probably some of these changes are due to actual variations in the wave-lengths of the lines considered, but many of them are undoubtedly due to changes of intensity of the components of blends. In the single-prism spectrograph most of the lines observed are blends between the components of which there are relatively great differences in wave-length. It is

TABLE 31

DIFFERENCES IN WAVE-LENGTH; CLASS B STARS

SOURCE	WAVE-LENGTH	REMARKS	ζ ORIONIS B			η URSÆ MAJORIS B3			β TAURI B8			α LEONIS B8			MEANS	
			Δλ	I	WT.	Δλ	I	WT.	Δλ	I	WT.	Δλ	I	WT.	Δλ	WT.
Hζ	3889.15					−0.08	4.0	4	+0.06	3.3	8	+0.18	1.4	8	+0.08	20
K	3933.83	I = 1000 in ⊙	−0.09	1.8	36				−0.01	2.3	43				−0.05	79
He	3964.88		−0.15	2.0	2										−0.15	2
He	3970.18	I = 5				+0.22	4.0	4				−0.11	1.9	19	−0.05	23
He	4026.37		0.00	3.6	8	−0.08	3.1	26	−0.08	2.6	35				−0.07	69
Si	4089.00		+0.07	4.0	28										+0.07	28
	4097.47		−0.07	2.0	4										−0.07	4
Hδ	4101.92		+0.15	4.6	25	0.00	4.7	20	−0.02	4.1	37	0.00	2.1	27	+0.03	109
He	4116.30		+0.03	3.5	23										+0.03	23
He	4121.02		−0.11	1.0	1	0.00	2.0	2	+0.14	1.3	6				0.00	9
Si	4128.22	Strongest silicon line							−0.03	1.9	30				−0.03	30
Si	4131.04								+0.19	1.9	28				+0.19	28
He	4143.92		+0.03	2.2	6	+0.25	3.2	13	+0.17	1.0	4				+0.18	23
	4267.30					+0.14	1.3	4	+0.20	1.7	13				+0.19	17
Hγ	4340.63	I = 20 in ⊙	−0.07	5.3	27	0.00	4.0	25	−0.06	3.9	39	+0.05	2.2	35	−0.02	126
He	4388.10		+0.14	2.1	16	+0.13	3.1	13	+0.04	1.3	5				+0.12	34
Ti	4395.19	Enh. 5 : 9							+0.09	1.0	2				+0.09	2
He	4471.68		−0.09	4.3	31	−0.16	3.5	16	+0.08	2.4	24				−0.05	71
Mg	4481.40	Enh. 0 : 10				−0.11	3.0	7	−0.02	2.5	29				−0.04	36
Fe	4549.64	Enh. 1 : 7							+0.03	1.0	1				+0.03	1
Si	4552.76		+0.12	1.0	6	+0.30	2.0	2							+0.17	8
	4647.74		+0.20	2.0	6										+0.20	6
	4649.42		−0.09	2.9	18										−0.09	18
	4650.63		+0.39	1.5	3										+0.39	3
	4686.00		+0.25	2.0	4										+0.25	4
He	4713.31		+0.12	2.4	14	−0.13	2.0	2							+0.09	16
Hβ	4861.53		−0.30	3.5	16	−0.05	3.6	20	−0.19	3.1	18	−0.03	2.0	36	−0.11	90
He	4922.10		+0.19	1.8	5										+0.19	5

therefore to be expected because of the changes of relative intensity in the components of these blends that changes in wave-length with spectral type great enough to be measured easily will be found in stellar spectra made with the single-prism spectrograph.

In Table 33, there are eleven lines, indicated in the first column by asterisks, that show a well defined variation in wave-length from Class F5 to Class Mb; and others which show variations large enough to be measured. Judging from these results the single-prism spectrograph, in view of its light efficiency as compared with a three-prism instrument, may be preferable for use in determining spectral types on the basis of wave-length variations.

DISCUSSION OF ERRORS AFFECTING THE FINAL RESULTS

It is of value in connection with the above velocities of solar type stars to study those

TABLE 32

DIFFERENCES IN WAVE-LENGTH; CLASS A STARS

SOURCE	WAVE-LENGTH	REMARKS	α LYRÆ A0 Δλ I WT.	γ URS. MAJ. A0 Δλ I WT.	β LEONIS A2 Δλ I WT.	δ LEONIS A2 Δλ I WT.	α AQUILÆ A5 Δλ I WT.	MEANS Δλ WT.
Ti	3900.71	Enh. 4:10	−0.04 0.7 13					−0.04 13
Ti	3913.64	Enh. 4:10	0.00 0.8 16					0.00 16
K	3933.83	I = 1000 in ⊙	0.00 6.5 55	−0.06 2.3 32	+0.05 2.9 19	−0.08 4.9 21		−0.02 127
Fe	4045.98	I = 30 in ⊙	+0.04 0.9 20		−0.24 1.0 17			−0.08 37
Ti	4053.98	Enh. 1:5			+0.18 1.0 1			+0.18 1
Fe	4063.76	I = 20 in ⊙	+0.03 0.8 15					+0.03 15
Fe	4071.91	I = 20 in ⊙	+0.03 0.5 5		+0.10 1.0 10			+0.08 15
Se	4077.89	Enh. 8:10. I = 8 in ⊙			−0.14 1.0 16			−0.14 16
Hδ	4101.92		+0.02 6.9 29	−0.03 4.9 36	−0.04 3.2 20	−0.05 5.2 21	+0.10 3.5 33	+0.01 139
Fe	4144.04	I = 15 in ⊙			−0.18 1.0 19			−0.18 19
Y	4167.69	I = 4 in spark			0.00 1.0 5			0.00 5
Sr	4215.69	Enh. 8:10			+0.05 1.0 14			+0.05 14
Fe	4233.33	Enh. 0:4–5	−0.01 0.8 24		+0.19 1.0 16			+0.07 40
Fe	4238.97	I = 5 in ⊙			+0.10 1.0 1			+0.10 1
	4247.00	I = 5 in ⊙			+0.02 1.0 14			+0.02 14
Fe	4250.94	I = 8 in ⊙			+0.05 1.0 6			+0.05 6
Fe	4260.50						+0.02 1.0 9	+0.02 9
Fe	4325.94	I = 8 in ⊙			−0.01 1.0 16			−0.01 16
Hγ	4340.63	I = 20 in ⊙	−0.03 6.8 38	+0.05 5.4 41	−0.01 3.1 20	−0.09 4.5 24	+0.02 3.3 38	−0.01 161
Cr	4351.95	I = 10			+0.03 1.0 12			+0.03 12
Y	4375.11	Enh. 7:10; I = 100 in ⊙			−0.03 1.0 9			−0.03 9
Ti	4395.19	Enh. 5:9	−0.09 0.6 11					−0.09 11
V	4474.92	I = 5 in spark			+0.30 1.0 1			+0.30 1
Mg	4481.40	Enh. 0:10	−0.01 3.8 46	−0.21 1.7 6	+0.12 2.4 23	+0.29 2.2 23	−0.09 1.8 34	+0.04 132
Fe	4508.46	Enh. tr.:5			+0.10 1.0 2			+0.10 2
Fe	4549.64	Enh. 1:7	+0.01 1.1 19					+0.01 19
Fe	4584.02	Enh. 1:8			+0.01 1.0 4			+0.01 4
Hβ	4861.53		+0.02 6.3 24	+0.01 4.8 28	+0.03 2.3 13	+0.03 4.4 22	−0.09 3.0 22	0.00 109

TABLE 33

MEAN WAVE LENGTHS FOR CLASSES F5 TO Mb

COMPUTED λ, COR.	INTENSITY	F5 (3) Δλ	F5 (3) WT.	F8p (1) Δλ	F8p (1) WT.	K0 (10) Δλ	K0 (10) WT.	Kp (1) Δλ	Kp (1) WT.	K2 (1) Δλ	K2 (1) WT.	K5 (2) Δλ	K5 (2) WT.	Mb Δλ	Mb WT.
3987.05	15	+0.01	41			+0.13	71	+0.19	5	+0.16	12	+0.19	2		
4005.39	15	+0.08	119	+0.13	40	+0.01	130	+0.01	21	−0.01	28	−0.01	11		
4020.40	15	−0.07	1			+0.08	110	+0.08	22	+0.08	24	+0.14	18	+0.08	2
4030.83	15	−0.05	97	+0.01	27	−0.04	104	−0.10	21	0.00	18	−0.15	9	+0.07	3
4033.15	13	−0.04	74	+0.01	33	0.00	115	0.00	24	+0.02	25	−0.04	12	+0.15	2
4057.74*	13	+0.04	45	+0.03	2	0.00	98	+0.01	12	0.00	26	−0.05	16	−0.15	10
4063.88	15	−0.15	109	−0.08	37	−0.04	33	−0.10	1	−0.01	1	−0.19	5	−0.08	8
4071.90	15	−0.04	86	−0.03	28	+0.02	117	+0.03	15	+0.04	18	+0.05	8	−0.21	14
4092.72	14	−0.05	33	−0.01	26	0.00	199	−0.03	30	−0.02	30	−0.02	53	−0.07	33
4118.89	13	−0.04	92	−0.12	36	−0.09	122	−0.07	16	−0.03	16	−0.10	36	−0.06	30
4126.09	11	+0.15	3	+0.26	2	+0.08	129	+0.05	19	+0.06	20	+0.01	38	+0.09	17
4127.97	13	+0.22	82	+0.06	25	+0.07	195	+0.08	29	+0.06	30	+0.10	45	+0.09	38
4132.45	15	+0.11	86	+0.10	40	+0.01	182	−0.02	29	−0.03	29	−0.05	37	+0.01	24
4137.37*	8	+0.13	25	+0.39	3	−0.02	120	−0.08	25	−0.08	25	−0.05	30	−0.10	27
4143.07	15	−0.13	124	−0.11	36	+0.10	4							+0.24	3
4152.30*	15	0.00	35	+0.01	29	+0.09	150	+0.08	27	+0.06	25	+0.12	38	+0.31	20
4154.49	14	+0.05	102	+0.09	35	−0.02	54	+0.07	2	0.00	12			−0.28	4
4156.73*	15	+0.05	66	−0.10	39	−0.06	141	−0.12	20	−0.08	20	−0.17	41	−0.14	26
4167.59	15	0.00	82	−0.09	26	−0.04	183	−0.13	29	−0.03	28	+0.02	43	+0.13	7
4182.05	13	+0.05	91	−0.01	35	−0.03	8							0.00	23
4198.69	15	+0.07	127	+0.10	40	+0.01	195	−0.04	29	−0.03	30	+0.01	40	−0.08	25
4202.30	15	+0.01	87	+0.11	38	+0.01	189	−0.02	26	−0.01	30	+0.02	45	−0.09	32
4207.15*	10	+0.16	2	0.00	21	−0.10	86	−0.12	19	−0.14	11	−0.10	45	−0.17	34
4215.89	14	0.00	127	+0.01	40	−0.04	131	−0.08	6	−0.05	11	−0.01	45	0.00	40
4229.85	13			+0.12	3	+0.23	166	+0.25	10	+0.23	22	+0.28	29	+0.02	4
4233.55	14	−0.03	131	−0.01	40	−0.15	83	−0.20	13	−0.10	9	−0.18	28		
4243.21*	13	−0.42	23	−0.60	19	−0.03	108	−0.02	7	−0.02	10	+0.06	9		
4250.67	14	+0.01	102	0.00	39	−0.01	200	+0.03	30	+0.05	23	+0.09	50	+0.05	37
4260.61	15	+0.03	86	+0.10	38	+0.03	178	+0.06	26	0.00	29	+0.06	49	+0.09	31
4271.84*	15	−0.13	123	−0.15	40	+0.03	208	+0.05	28	+0.02	30	+0.08	49	+0.12	33
4280.44	13					+0.12	198	+0.15	30	+0.08	27	+0.19	50	+0.24	37
4282.79	14	+0.02	71	+0.01	36	+0.04	183	+0.02	29	+0.02	29	+0.10	59	+0.10	38
4289.78*	15	+0.36	121	+0.38	40	+0.03	208	+0.05	30	+0.01	27	+0.04	59	−0.01	39
4300.91*	13	+0.05	85	+0.17	28	+0.19	126	+0.18	24	+0.22	15	+0.17	53	+0.19	40
4305.80	17	+0.04	56	+0.01	37	+0.01	113	+0.01	7	−0.05	9	+0.12	24	+0.23	32
4308.19	11	−0.07	57	−0.09	27	−0.09	168	−0.11	20	−0.13	24	−0.13	48	−0.05	25
4314.95	13	−0.12	89	−0.14	39	−0.01	200	−0.06	30	−0.02	24	−0.03	60	−0.09	40
4323.73	15					−0.04	109	−0.15	8	−0.07	21	−0.14	13		
4337.79	11	+0.01	51	+0.11	40	−0.06	192	+0.02	30	−0.05	23	−0.07	60	−0.05	40
4340.63	15	+0.12	121	+0.24	36	+0.05	110	+0.11	5	+0.01	2	+0.08	46	−0.01	40

TABLE 33

MEAN WAVE LENGTHS FOR CLASSES F5 TO Mb — CONTINUED

COMPUTED λ, COR.	INTENSITY	F5 (3) Δλ	WT.	F8p (1) Δλ	WT.	K0 (10) Δλ	WT.	Kp (1) Δλ	WT.	K2 (1) Δλ	WT.	K5 (2) Δλ	WT.	Mb Δλ	WT.
4352.19	12	−0.21	76	−0.43	22	−0.34	122	−0.31	3	−0.28	13	−0.39	22		
4395.37	9	−0.15	63	−0.05	20	+0.09	130	+0.10	24	+0.14	12	+0.01	41	−0.12	33
4404.94	15	−0.10	58	+0.02	24	−0.08	209	−0.04	30	−0.05	30	−0.10	58	−0.05	30
4415.31*	14	+0.06	60	+0.11	32	−0.10	199	−0.11	30	−0.06	30	−0.18	60	−0.20	39
4435.42	9	+0.02	11	+0.01	17	−0.07	5	+0.27	1					+0.05	27
4462.07*	11	−0.16	33	−0.24	21	−0.04	177	−0.07	28	−0.08	21	−0.03	55	+0.01	37
4549.81	8	−0.08	66	−0.04	24	−0.11	95	−0.15	9	−0.10	5	+0.20	31	−0.43	20
4667.61	9	−0.02	10	−0.22	1	+0.01	98	+0.03	14	−0.03	7	+0.09	35	+0.53	14
4861.43	11	−0.02	55	−0.20	15	−0.08	99	0.00	9	−0.06	14	+0.04	32	−0.05	14
4957.76	11	−0.06	16	+0.15	10	+0.06	87	+0.06	13	+0.05	10	+0.13	35		

sources of error which have not been investigated closely up to the present time, so far as the writer knows. These sources of error include effects due to defective guiding, atmospheric disturbances, and temperature changes in the large mirror. The effects due to defective guiding will be considered in connection with duration of exposure time, variations in atmospheric dispersion, and variations in hour angle.

Only those stars whose velocities seemed to be constant were used in the investigation of errors, hence about one hundred and fifteen observations were at hand. It was assumed then in the long run that the sets of plates for each star represented average conditions, and the residuals for each plate from the mean of the rest were used in the study of the various sources of error investigated. In some cases the algebraic residuals were combined for the study of systematic errors; and in other cases, the absolute residuals were used, for the determination of the relation of the average error to the sources under investigation.

Atmospheric Dispersion. Atmospheric dispersion, by converting the star image into a spectrum, often causes considerable distortion in the stellar image, depending largely upon the position of the star in question. Since the slit is parallel to the equator it is the dispersion in declination only that may be a source of error. The refraction of a celestial object acts along the vertical circle and is a function of the tangent of the zenith distance, z. The effect, then, in declination is a function of the product, tan z by cos q, where q represents the parallactic angle. This product is called below the refraction factor. With the aid of the globe the angles z and q, corresponding to each observation, were determined by means of protractor and tape to the nearest degree, and the refraction factor was then formed. Only the absolute residuals seem to give any effect depending upon magnitude of refraction factors. To bring out the relation between the absolute plate velocity residuals, taken without regard to region, and the so-called refraction factors, these were plotted respectively as ordinates and abscissæ. Not enough observations with negative refraction factors were available to give any result, but for positive values, the average plate residual of 1.0 km. for a value of the refraction factor near 0.10 increased to 2.9 km. at 0.55, and then gradually decreased to 2.5 km. at 1.10. This change in magnitude of the residuals with refraction is well indicated.

The form of the curve of the variation of absolute velocity residuals with refraction factors is undoubtedly influenced by variation of seeing with zenith distance. As a star deviates in position from the meridian, the spectrum, caused by atmospheric dispersion, becomes more and more distinct until a certain zenith distance is

reached, beyond which point there is a tendency for the colors to blend together, due to poorer seeing. Such being the case, it seems reasonable to believe that the slit is in general more uniformly illuminated for these greater zenith distances than for some that are smaller, thus rendering results more consistent. This fact would account for the downward slope of the curve beginning at a refraction factor, 0.55.

Errors due to this source would probably be entirely eliminated by the use of a parallelopiped as suggested by Professor R. H. Curtiss in Volume I of these *Publications*.

Duration of Exposure Time. It was thought that possibly the velocity residuals varied with the length of exposure time of a plate, due to the chance that the star image might be kept off the center of the slit in one direction during a greater part of a short exposure. A plot of absolute velocity residuals against length of exposure time, the latter varying from two to twenty minutes for the stars considered, shows that such residuals decrease with exposure time up to about fifteen minutes. With exposure of more than fifteen minutes duration the velocity residuals show practically no variation. For short exposures of less than one minute, this effect would be relatively large.

Atmospheric Disturbances. The seeing was estimated by the observer at the beginning of each exposure. Perfect seeing was denoted by 5, and the poorest by 1. It is very seldom that the seeing was recorded as being perfect, and the average estimate was between 2.0 and 2.5. In the general table, given under each star, these factors are given in the last column. A plot of the absolute values of the velocity residuals against their corresponding seeing factors shows no appreciable effect. This does not mean, however, that other sources of error are not affected by atmospheric disturbances. It has been pointed out that the star image drawn out by atmospheric dispersion is probably also affected by atmospheric disturbances, since the colors in the stellar refraction image intermingle more completely when the seeing is poor. Also errors due to poor centering of the image on the slit, especially during very short exposures, are reduced by poor seeing.

Hour Angle. A plot of the hour angles against either the algebraic or absolute velocity residuals, shows no effect. J. B. Cannon, in the *Journal of the Royal Astronomical Society of Canada*, Vol. 10, p. 185, 1916, tabulated the hour angles of all the plates of several stars and the residuals of the plates, but did not obtain any positive result.

Since ninety per cent of the stars studied by the writer were observed over a wide range of hour angles west of the meridian, any considerable effect due to this cause should show itself readily.

Distortion of Large Mirror. The temperature of the large mirror and the optical parts of the spectrograph is maintained practically constant, throughout the day, by the use of a large temperature case which encloses the lower end of the telescope tube. It is desirable that the temperature case should be removed when the difference between the temperature registered within the case and that of the dome is a minimum. However, this procedure is not always possible. Occasionally there are large differences in temperature between the mirror and the outside air, during the early part of the night at least. The temperature near the prism within the spectrograph, denoted by T_3, is maintained nearly constant by the use of a thermostat, and represents the temperature of the mirror before the case was removed. When the mirror is exposed the distortion of its surface becomes a function of the difference between the outside temperature, T_1, and that in the prism box, T_3. Thus we have a means of studying to what extent the velocity residuals are affected by the distortion of the mirror, by plotting these residuals against the temperature differences, $T_1 - T_3$. A plot of either the algebraic, or the absolute residuals, against the temperature differences, $T_1 - T_3$, does not give a positive result.

Experience. It was thought possible that the magnitude of the plate residuals would decrease with the observer's increasing experience in plate measuring. However, no unmistakable effect of this kind was found in the results of this program. Apparently the writer's proficiency in measurement had developed to a stationary state before the velocity determinations of the present pro-

gram were made. Before making the measures on the Potsdam velocity stars, the writer had studied the wave-lengths of 116 titanium spark lines on twenty-six single-prism spectrograms, a program involving over thirty-six thousand settings.

ACCURACY OF RESULTS

The accuracy of the observer's velocities is best brought out by a study of the probable errors for single plates. The average value of the probable error of a plate based upon the internal residuals of all the plates of a star has been called E_1 in this paper. This quantity differs strikingly in different stars, depending greatly on the sharpness and number of lines. In some of the stars in the present program it is the predominating element in the total probable error; in others it is relatively much less prominent. In general it can not be used alone in comparing the accuracy of the results obtained with different instruments. The probable error, E, of a plate of average weight based on the plate residuals may be called the total probable error of a plate. In it are combined the elements of error in E_1 and also those which vary from plate to plate such as personal equation, guiding error, incomplete identity of source, temperature and flexure changes during exposure, and changes in the photographic film. This latter part of the total probable error of a plate is designated as E_2 in this paper and is defined by the relation, $E_2^2 = E^2 - E_1^2$. In general E_2 when well determined will be closely the same for all classes of spectra with the same instrument, other things being equal. Probably it would tend to be greater when the lines are wider, for in such cases there is chance of greater variations in personal equation. In comparing the work of different spectrographs, values of E should be used for the same star or for stars with very similar spectra. When E_2 is well determined for a given spectrograph, variations from the established value give indications of special conditions such as velocity variation in the source. E_2 may be used also in comparing the accuracy obtainable with different instruments. Values of E_1, E and E_2 for the stars studied in this paper, together with spectral class and average exposure time are given in the following table of

AVERAGE PROBABLE ERRORS OF SINGLE PLATES

STAR	E_1	E	E_2	EXPOSURE TIME	SPECTRAL CLASS
	km.	km.	km.	min.	
β Tauri	±1.96	±2.84	±2.04	5.3	B8
ζ Orionis	2.92	4.99	4.05	6.1	Bo
α Leonis	4.30	5.23	2.99	4.2	B8
δ Leonis	5.95	4.90	*	7.4	A2
β Leonis	2.77	3.46	2.07	7.8	A2
γ Ursæ Majoris	3.58	5.00	3.49	7.5	Ao
η Ursæ Majoris	4.58	6.76	4.97	4.1	B3
α Lyræ	1.36	1.67	0.97	1.6	Ao
α Aquilæ	6.3	5.84	**	4.8	A3
β Cassiopeiæ	0.89	2.12	2.04	12.8	F5
α Cassiopeiæ	0.38	1.69	1.65	8.0	Ko
γ Andromedæ	0.44	0.89	0.77	13.0	Kp
α Arietis	0.41	1.80	1.75	9.7	K2
α Persei	0.53	1.51	1.41	4.4	F5
α Tauri	0.62	1.60	1.47	6.7	K5
α Canis Minoris	0.48	1.58	1.51	2.8	F5
β Geminorum	0.57	1.04	0.87	4.4	Ko
γ Leonis	0.49	1.72	1.65	15.3	Ko
α Bootis	0.48	1.64	1.57	3.8	Ko
ϵ Bootis	0.46	1.21	1.12	11.6	Ko
β Ursæ Minoris	0.55	1.95	1.87	10.7	K5
α Serpentis	0.59	0.95	0.74	12.8	Ko
γ Cygni	0.39	0.67	0.54	7.7	FSp
ϵ Pegasi	0.47	0.94	0.81	13.5	Ko
β Pegasi	±0.73	±3.07	±2.98	10.1	Mb

* $3.4\sqrt{-1}$, ** $2.4\sqrt{-1}$.

It has been shown above that atmospheric dispersion and sources of error which are not averaged out in short exposures have an appreciable effect upon probable errors. Atmospheric dispersion is not a constant factor for any star, though stars which average farthest from the zenith are more strongly affected. Exposure time is in a large measure a constant factor for any given instrument and any given

star. In short exposures errors due especially to poor guiding and inaccurate focusing become relatively more important. Hence in observations of brighter stars we may expect to encounter greater values of E_2 and in some degree of E_1. In order to study the relation between exposure time and values of E_2, the author has plotted the corresponding values of these two quantities for stars with spectra in Classes F5 to Mb, contained in columns four and five of the table just given. Excluding stars of doubtful value because of suspected velocity variation, the graph shows a dependence of E_2 on exposure time as indicated in the table below. The value of E_2 begins at ± 1.5 km. for one minute exposures and falls to about ± 0.80 km. for fourteen minute exposures and probably would continue at about this value for those of longer duration. Since nearly all exposures on regular programs exceed fifteen minutes or can be made to do so profitably, and since, with a knowledge of the danger of this error, guiding during shorter exposures can be more carefully done, it may be assumed that the value of E_2 for the writer with the Ann Arbor single-prism spectrograph is about ± 0.75 km.

VALUES OF E_2 FOR DIFFERENT EXPOSURE TIMES

EXPOSURE TIME	E_2
2 min.	± 1.4 km.
4	1.3
6	1.1
8	1.0
10	0.9
12	0.9
14	± 0.8

In drawing the curve from which the data of this table were derived it was necessary to take into account the possibility of small velocity variations for some of the stars in the preceding table. It is difficult to establish reliable criteria for the rejection or inclusion of stars in this connection and to that extent the results here given are uncertain. It was decided to include results for α Cassiopeiæ, though there exists a slight chance of its velocity variation. The results for α Arietis, β Ursæ Minoris, γ Leonis, β Cassiopeiæ, and β Pegasi were excluded because the velocities of the first two were suspected of variation over a small range, of the second two over a larger range, while the last named is almost certainly variable.

The values of E_2 for the stars of spectral classes Bo to A5 studied in this paper are not strong enough to bring out the above relation between exposure time and E_2. Excluding two stars, ζ Orionis and η Ursæ Majoris, which are probably binaries, the average value of E_2 for an average exposure time of six minutes is ± 0.82 km. and for all stars in this group ± 1.48 km. in which imaginary values are considered negative. This agrees farily well with the results above for stars with more measurable spectra.

It may be considered then that the value of E_2 for the writer's measures is ± 0.75 km. for exposures of fifteen minutes or more. The average value of E_1 for the sixteen stars with spectra in types F5 to Mb is ± 0.53 km. Combining these two elements of probable error we find that for spectra having many fairly measurable lines with exposures of fifteen minutes or over the total probable error for a single plate is ± 0.92 km. for the writer's observations. The average value of the total probable error of a single plate for the ten stars not definitely suspected of binary character in Classes F5 to K5 is ± 1.21 km.; but the average exposure time for these stars is only 8.6 minutes. For stars requiring fifteen or more minutes' exposures, the total probable error of a single plate of average weight would be about 0.30 km. less, indicating again the value of ± 0.92 km. as above. For the most measurable stellar spectra found in the sky, such as γ Andromedæ and γ Cygni, the total probable error for exposures of fifteen minutes or more would be on the average in the neighborhood of ± 0.85 km. The smallest value actually observed is ± 0.67 km., for γ Cygni which happens to be better than the predicted average.

It remains to compare the probable errors expressing the accuracy of the writer's velocities with those of other observers and other instruments. From eleven plates of the brightest component of β Monocerotis made with the spectrograph used by the writer, Doctor Merrill derives a value of ± 0.84 km. for the total prob-

able error of a single plate. This result for a Class Bp spectrum is unexpectedly smaller than the writer's value (±0.92 km.) for solar stars. The writer's value compares favorably with the following values for solar type spectra derived with the single-prism spectrograph of the Lick Observatory; for W Sagittarii, ±0.90 km.; for X Sagittarii, ±1.80 km.; for Y Sagittarii, ±2.10 km., but these are all southern stars with only fair lines. From thirty-four spectrograms of Arcturus, made with the Ottawa single-prism spectrograph, Plaskett derived a total probable error of a single plate of ±0.70 km., but all of these plates were secured on four dates only, giving less chance for instrumental variations between plates. For seven stars with good lines studied with the three-prism Mills Spectrograph of the Lick Observatory, the total probable errors of single plates vary from ±0.47 km. for η Pegasi to ±0.79 km. for α Geminorum. But the best results for this and other three-prism instruments would be somewhat better than these. From forty-six plates of β Aurigæ, made with the Mellon Single-Prism Spectrograph of the Allegheny Observatory, Professor R. H. Baker found a value of E_2 at ±1.10 km. Since the lines of this star are double they are probably of a character unfavorable to high accuracy. Doctor Baker concluded that the probable error introduced by comparing the star lines with the spark lines did not exceed one kilometer for the average plate made with the Mellon Spectrograph. The writer's value of ±0.75 km. for the Ann Arbor equipment, indicates that these two instruments give results of similar accuracy.

A comparison of the accuracy of the writer's velocity results with that of other observers and other spectrographs is not in general favorable to the Ann Arbor equipment for four reasons. Nearly all of the spectrograms were made by inexperienced observers. The writer had had no previous experience in radial velocity work and relatively little in plate measuring. For all but one of the stars the average exposure was less than fifteen minutes. Nearly all of the spectra discussed in this paper could have been improved by using a longer slit. It is true, however, that most of the plates were made on slow emulsions of relatively fine grain and good contrast. From all points of view the accuracy attainable with the equipment of this Observatory is satisfactory and the comparison with the results of others reassuring. At the same time our results have brought out the importance, not always realized, of guiding very carefully, especially on short exposures, of observing no further from the zenith than necessary, especially when the seeing is good, and of using slit-widths as small as circumstances will allow, even though the resulting resolution is not needed.

SUMMARY

In this paper the writer has discussed the radial velocities of twenty-six of the fifty-one early Potsdam velocity stars. These twenty-six were chosen because it was not known at the time that the velocity of any of them was variable. The discussion is based on velocities derived by the writer from 454 spectrograms made with the single-prism spectrograph of the Detroit Observatory and on velocity results obtained by many other observers beginning with Vogel and Scheiner.

From his own velocities, the writer concludes that the velocities of β Libræ and β Pegasi are variable. For the former a period of eighty days, a range of sixteen kilometers, and a center of mass velocity of −37 km. is indicated. For the latter a period of fifty-two days with a range of eleven kilometers is suggested. The variation of the former has been announced by Lee. Four stars, β Cassiopeiæ, γ Leonis, ζ Orionis, and η Ursæ Majoris, are probably velocity variables with very small range. Four other stars, γ Ursæ Majoris, β Ursæ Minoris, α Arietis, and α Cassiopeiæ, give evidence of possible velocity variation of very small range.

A number of double absorption lines were observed and measured in the spectra of β and δ Leonis and α Aquilæ. The doubling is probably due to central reversal of wide absorption lines. In each star the separation of components of doubled lines increases in a simple linear relation with wave-length but with different constants for the different stars. The equation expressing this relation for each star is given.

The systematic correction for the writer's radial velocities are as follows: for Classes Bo − B8, +1.6 km.; Ao − A5, +2.9 km.;

F5 — F8, +3.6 km.; K0 — K5, +2.5 km.; average for all classes, +2.8 km.

From the results of eight observers, based on many velocities, the average systematic correction to velocities determined with the Detroit Observatory equipment is found to be −0.01 km.

The early Potsdam velocities are found to be about five kilometers too small algebraically. This correction extends through the spectral classes, decreasing one or two kilometers perhaps from Class B to Class K.

Wave-lengths are derived for all lines employed in all the spectra discussed except those of β Libræ. Eleven lines were found whose wave-lengths show a well defined progressive variation from Class F5 to Class Mb. Others show smaller variations of the same kind. A few are quite irregular and some show pronounced divergences from the wave-lengths for the moon plates.

Errors or residuals in velocity determinations are found to increase both with atmospheric dispersion at right angles with the slit and with decreased exposure time when such exposures are less than fifteen minutes in duration. Poor seeing probably reduces these effects. No variations in errors were found depending on hour angle alone, temperature changes in the large mirror, and measuring experience.

The total probable error for a single average plate and the element of that error depending on spurious changes from plate to plate in the measured positions of star and comparison lines were found to decrease with increasing exposure up to about fifteen minutes. The value of the total probable error of a single average plate with many good lines was ±0.92 km. for exposures of fifteen minutes or more and the element of this error depending on spurious changes from plate to plate was ±0.75 km. The smallest total probable error for a single average plate was ±0.67 km., for γ Cygni.

The accuracy of the results obtained with the Detroit Observatory equipment in this case by an inexperienced observer, is satisfactory when compared with the results secured with other instruments.

The writer desires to acknowledge the helpful supervision of Professor R. H. Curtiss throughout this work on the Potsdam stars and during the preparation of the results for publication.

Ann Arbor, Michigan, 1917.

THE SPECTRUM OF ALPHA CANUM VENATICORUM

By C. C. KIESS

The spectrum of α (12) Canum Venaticorum (1900.0, $\alpha = 12^h\ 51^m.4$; $\delta = +38^\circ\ 52'$) has been studied by Miss Maury[1], Lockyer and Baxandall[2], Ludendorff[3], and by Belopolsky[4]. The Harvard Classification assigns the star to Class Ap, the peculiarity consisting in the presence of numerous faint metallic lines in the spectrum which "appear to be peculiar in wave-length," and also in the strength of the silicon lines at λ 4128.5 and λ 4131.4. Lockyer and Baxandall describe the spectrum as of the Markabian type (α Pegasi), except for the numerous faint lines, chief among which are lines at wave-lengths 3954.3, 4076.5, 4136.3, 4192.0, and 4376.8. Ludendorff was the first to note that the faint lines of the spectrum are variable in intensity. This fact was later independently discovered by Belopolsky, who, to date, has published the most thorough study of the spectrum of the star. Baxandall, using the wave-lengths determined by Belopolsky, has shown that a number of them agree with the stronger lines of the spectrum of europium. Lastly, Guthnick and Prager[5], from photometric observations made with a photo-electric cell, have announced that the star is periodically variable, the period agreeing with that given by Belopolsky and the range in brightness being 0.051 magnitude.

Belopolsky's researches have shown that prominent among the faint lines in the spectrum of α Canum Venaticorum are two groups of lines which vary in intensity. When the lines of the first group are strong those of the second group are weak, and vice versa. In the accompanying table are listed the two groups of lines as published by Belopolsky:

GROUP I	GROUP II
λ = 398.4 μμ	λ = 407.6 μμ
403.8	412.3
413.0	423.4
420.5	426.2
429.1	430.4
438.6	451.6
444.8	455.6
451.5	481.5
454.1	492.2
456.2	

The period in which the variation takes place is 5.50 days. Furthermore, the velocities given by some of the variable lines are not constant, but vary in the 5.50 days period. Assuming the variable velocity to be the result of the orbital motion of a gaseous ring or satellite about a more massive companion, Belopolsky finds, from a solution for the orbit, that the velocity of the center of mass of the system differs considerably from the constant velocity given by the hydrogen, iron, silicon, calcium, and magnesium lines of the spectrum. It should be noted here that Ludendorff's variable lines are at wave-lengths 4238.97, 4351.93, and 4472.88. These are not given in Belopolsky's lists, but are present in Table 6 of this paper.

In response to Belopolsky's telegram[6] announcing the variability of the lines in the spectrum of α Canum Venaticorum, the star was placed on the observing program for the one-prism spectrograph of the Detroit Observatory. During the months of June and July, 1913, a series of thirty-seven spectrograms was secured, many of these being on consecutive dates. In 1914, seventeen more observations were made. To this number

[1] *Harvard Annals*, Vol. 28, page 96, 1897.

[2] *Proceedings of the Royal Society*, London, Series A, Vol. 77, page 550, 1906.

[3] *Astronomische Nachrichten*, Vol. 173, page 1, 1906.

[4] *Bulletin de l'Académie Impériale des Sciences de St. Pétersbourg*, Series VI, Vol. 7, page 689, 1913; also *Astronomische Nachrichten*, Vol. 196, page 1, 1913.

[5] *Veröffentlichungen der Königlichen Sternwarte zu Berlin-Babelsberg*, Vol. 1, page 44, 1914.

[6] *Harvard Bulletin*, No. 519.

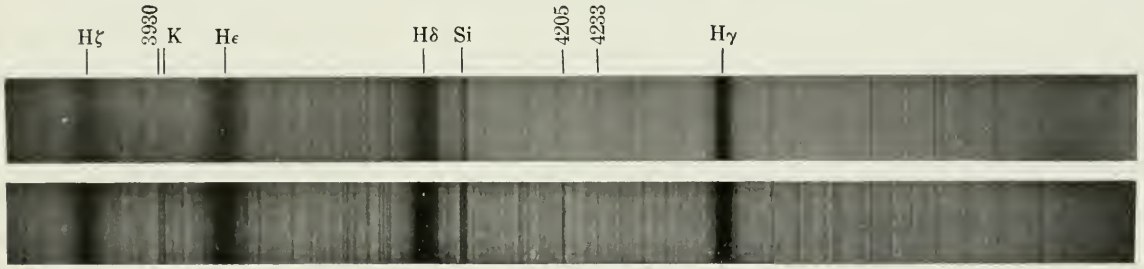


Plate D. Spectra of α (12) Canum Venaticorum

were added fourteen observations made by the writer in March, April, May, and June, 1917.

The one-prism observations are given in Table 1. The headings of the columns are self-explanatory. The 1913 observations were all made on Seed 23 plates, the exposure times being, on the average, four minutes. The 1914 spectrograms were made on Seed Red Label Lantern Slide plates for which exposure times of eight minutes were required. These earlier plates were all secured with the original prism of the spectrograph[7]. The 1917 plates were secured with the new prism. For this last series of observations Seed Red Label Lantern Slide plates were used. Some of the plates were over-exposed to obtain that portion of the spectrum to the violet of He which is lacking on the earlier series. The spark spectrum of titanium was used as comparison spectrum.

In addition to the one-prism spectrograms described above there were available for the study of the star's spectrum five three-prism spectrograms secured at the Lick Observatory and kindly loaned to me by Director Campbell. These are listed in Table 2, which is similar in arrangement to Table 1. The first two plates cover the spectral region λ 4100 to λ 4600, with Hγ central, while the remaining three cover the region λ 4250 to λ 4700, with λ 4500 central.

All the plates were measured and reduced by the writer. The radial velocities of the star reduced to the sun are given in column 4 of Table 1 and in column 3 of Table 2 respectively. For the one-prism plates the velocities are based on the displacements of some of the lines given in Table 3, the number of lines used for each plate being recorded in column 5, Table 1. For the three-prism plates the velocities were derived from numerous very faint iron and titanium lines in addition to the lines of hydrogen and magnesium. The velocities derived from the displacements of these known lines give no indication of periodic variation, hence, the mean of all the determinations is adopted as the velocity of the star. It and other velocities determined elsewhere, are given in the following table:

RADIAL VELOCITIES OF α CANUM VENATICORUM

Pulkovo[8]	−6.5 km. per sec
Potsdam[9]	−0.3
Lick, Campbell[10]	−1.6
Lick, Kiess	+0.3
Ann Arbor	−0.87 ±0.37 km. per sec.

It should be mentioned that the velocity Belopolsky derives from the iron lines does not agree with that given by the hydrogen, silicon, and magnesium lines, being +0.8 km. per sec[8]. My measurements do not indicate that such a difference exists.

In addition to the known lines of Table 3, numerous very faint lines are present in the spectrum of the star. All those upon which good micrometer settings could be made, were measured for wave-length determinations. These settings were first corrected to reduce them to zero velocity, assuming that they shared the same velocity displacements as the known lines, and then the corrected values were introduced into Hartmann's formula to derive the wave-lengths of the unknown lines. The wave-lengths derived from the one-prism plates are brought together in Table 5. The number entered in the second column of the table indicates the number of plates on which the line was measured. The last column contains the suggested identifications of the lines.

Table 6 contains the results derived from the three-prism plates. Here the results for each plate are set forth in detail to illustrate the variable nature of the faint lines of the spectrum and to show the relative accuracy of the measures. In the columns giving the measures of the individual plates there are notes describing the intensity and character of the lines. The faintest lines measured are designated by oo, the figures 0, 1, 2, etc., indicating greater intensities. The letters have the following meaning: b = broad, bl = blend, d = diffuse. The last two columns of the table are similar to the first and last columns of Table 5. A comparison of the one-prism results with those derived from the three-prism plates shows that, in general, the two sets of measures agree to a tenth of an angstrom unit.

[7] *Detroit Observatory Publications*, Vol. I, pages 38 and 77.

[8] *Astronomische Nachrichten*, Vol. 196, page 7, 1913.

[9] *Astronomische Nachrichten*, Vol. 173, page 5, 1906.

[10] *Lick Observatory Bulletin*, Vol. 7, page 24, 1912.

The identifications are based on the wave-lengths given by Kayser in his *Handbuch der Spectroscopie*. The lines of titanium and iron were easily recognized by means of the comparison spectra, but these comprise only about one-seventh of the total number of the faint lines present in the spectrum. With the exception of a few lines attributable to chromium, manganese, and cobalt, those remaining are not characteristic of Class A stars. Baxandall[11] has already pointed out that the principal lines of the spectrum of europium agree well with lines observed by Belopolsky and characterized by him as variable lines of Group I. These lines and others agreeing in wave-length with europium lines are to be found in Tables 5 and 6. Furthermore, there are many coincidences between the star lines and the stronger lines of the spectra of gadolinium, terbium, and dysprosium, a group of the rare earth elements which are chemically related and which follow each other in the order of atomic number in the periodic system. Other rare earth elements whose presence in the star is suggested by agreements of star lines with lines in their spectra are: scandium, gallium, yttrium, lanthanum, praseodymium, samarium, and neoholmium. In fact, Stratton[12] has already suspected the presence of yttrium. Helium is not present, unless the line at λ 3964.9 may be attributed to it.

Early in the work of measurement of the Ann Arbor plates, before reference was made to the work of others, it became evident that certain of these faint lines which were measured on some of the plates were not visible on others. It was difficult to decide to what extent this behavior was the effect of exposure conditions, for some of the plates were overexposed, and the lines are exceedingly faint. But the effect was quite pronounced for the lines at wave-lengths 4132.7, 4205.3, and 4233.3. When the writer became aware of the work of Belopolsky an examination of the Ann Arbor measurements showed that several of the variable lines listed by the latter had been measured here.

During the measurement of the spectrograms, estimates of the relative intensity of each line were made, the standard of reference being the silicon line at λ 4128. From these estimates it was seen that many lines, additional to those observed at Pulkovo, are variable. A large number of the variable lines belong to either Group I or Group II, the variations in intensity occurring periodically in the 5.50 days period as found by Belopolsky. The lines which could be definitely classified are given in Table 4. Since most of the europium lines in the star's spectrum are to be found among the variable lines of Group I, it became a matter of interest to determine the origin of the lines of Group II. It was found that many of these agree closely with the stronger lines of terbium. Fainter lines of europium and terbium which agree approximately with the variable stellar lines are indicated by enclosing the laboratory wave-lengths in parentheses. Groups I and II may therefore be designated the Europium Group and the Terbium Group respectively, but it must be borne in mind that some of the variable lines are definitely not assignable to either of these two elements.

Many of the lines are manifestly blends, broadening and narrowing with increase and decrease in intensity. Such, for example, is the line at λ 4012.6. At maximum intensity it is as strong as λ 4128; at minimum it never becomes invisible as does λ 4205.3, the typical line of Group I. On several plates a very faint line is seen on the more refrangible edge of λ 4012.6. This is, in all probability, the titanium line at λ 4012.54. An interesting blend of the Terbium Group is at λ 3853.9. At maximum it is as strong as the neighboring silicon line at λ 3856.2, and at minimum it becomes invisible.

Belopolsky[13] has pointed out that the line at λ 4205.3 is displaced periodically with its variation in intensity. The evidence of this variation from the Ann Arbor plates is tabulated in Column 6, Table 1, and is shown graphically in Figure IV. Maximum positive displacement occurs when the line is of minimum intensity; and maximum negative displacement when it is of maximum intensity. The displacements are symmetrical with respect to the axis representing the constant velocity of the star. The dots in the figure

[11] *Observatory*, Vol. 36, page 440, 1913.

[12] *Observatory*, Vol. 36, page 461, 1913.

[13] Op. cit.

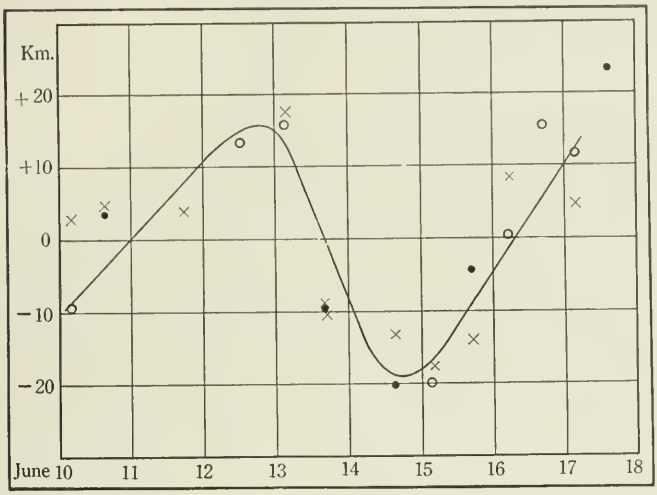


FIG. IV. DISPLACEMENTS SHOWN BY λλ 4205 AND 3930 IN SPECTRUM OF ALPHA CANUM VENATICORUM

represent the observations made between the dates June 10 and June 18, 1913. The circles represent the observations made prior to and subsequently to these dates and superposed on the curve by means of the 5.50 days period. The crosses represent velocities given by λ 3930.6, which is a variable line of Group I. It is seen that its displacements agree well with those exhibited by λ 4205.3. They are tabulated in column 7 of Table 1.

The only prominent line of Group II for which a large number of measures is available is at λ 4233.0. This is blended with the enhanced iron line at λ 4233.3, which renders the detection of periodic displacements difficult. The velocities yielded by this blend agree with those given by the prominent lines of the star's spectrum. The only other line of Group II of which enough observations were made to test for variability of displacement is at λ 4555.6. This, too, is a blend, but the measurements indicate that its position is variable. The velocities derived from the measures are given in column 8, Table 1. The displacements are too few to warrant the conclusion that the variability is periodic, conforming to the 5.50 days period.

The cause for the peculiar behavior of the variable lines in the spectrum is unknown. Belopolsky suggests that a gaseous ring or satellite is in orbital motion about the more massive star. If the chemical origins suggested for the variable lines are correct then it would seem as though this explanation would require two satellites or two condensations in the ring in which the vapors of europium and terbium are separated. To the writer a more plausible explanation is contained in a suggestion by Fowler,[14] that the level of the vapors of the rare earth elements whose lines are variable may change sufficiently to put them in or out of the absorbing region of the star's atmosphere. This view is supported by the relation, pointed out above, between minimum intensity and maximum positive displacement of certain variable lines. Granting that there is a periodic change in level of the vapors of europium and terbium, radial

[14] *Observatory*, Vol. 36, page 461, 1913.

motions and pressure effects combined may account for the velocity shifts observed.

SUMMARY

The chief results of this investigation of the spectrum of α Canum Venaticorum may be summarized briefly as follows:

1. Belopolsky's discovery of two groups of variable lines in the spectrum of α Canum Venaticorum and the period of variation have been confirmed.

2. His discovery that certain lines belonging to the two groups have variable velocities is also verified.

3. The identity of the variable lines with lines in the spectra of europium and terbium is indicated.

4. The identity of many of the faint lines with lines of the spectra of other rare earth elements such as gadolinium, dysprosium, yttrium, lanthanum, etc., is suggested.

5. The symmetry axis of the velocity curve of the variable lines of λ 3930.65 and λ 4205.20 is identical with the constant velocity of the star.

In conclusion I wish to express my thanks to Dr. R. H. Curtiss, of the Detroit Observatory, and to Director W. W. Campbell of the Lick Observatory, for placing at my disposal the spectrograms on which this study is based. To the former I am indebted also for valuable suggestions and criticisms made during the progress of the work.

Washington, D. C.
June 12, 1919.

TABLE 1

SINGLE-PRISM SPECTROGRAMS

PLATE NO.	DATE G.R. M.	PLATE SECURED BY	RADIAL VELOCITY REDUCED TO SUN	NO. OF LINES	VELOCITY FROM λ 4205.20	VELOCITY FROM λ 3930.65	VELOCITY FROM λ 4555.67	NOTES
	1913		km. per. sec.		km. per. sec.	km. per. sec.	km. per. sec.	
1928	June 2.670	Mellor	−0.2	8		− 9.9		
1929	2.686	Mellor	+3.0	8				
1947	4.682	Mellor	−4.4	8	−9.3	+ 3.1		
1948	4.693	Mellor	−0.6	7				
1955	7.650	Curtiss	+0.4	7				
1956	7.687	Curtiss	+0.7	8			− 1.1	Velocities mean
1957	7.717	Curtiss	−2.1	7		−10.3	− 5.0	of two measures
1962	8.637	Curtiss	−5.7	7				
1963	8.656	Curtiss	−2.6	7		−13.0	−18.6	Comparison
1969	9.659	Mellor	+0.9	7			+ 6.5	spectrum overexposed
1970	9.673	Mellor	−7.4	7	−20.7	−17.8		
1971	10.633	Albrecht	−2.2	10	+ 3.5	+ 4.8		
1982	11.678	Mellor	−7.2	7	− 0.1			Overexposed
1983	11.717	Mellor	+2.0	5	+14.6	+ 3.7		
1989	12.635	Albrecht	+6.5	7	+50.6		+ 3.2	
1997	13.670	Mellor	−0.2	7	− 9.6	− 9.4	+12.4	
1998	13.687	Mellor	+6.9	7			− 4.4	
2010	14.642	Curtiss	+5.2	7	−20.2	−13.2	− 2.8	
2011	14.657	Curtiss	−2.8	7				Overexposed
2019	15.698	Mellor	−0.4	7	− 3.7			
2020	15.710	Mellor	+6.6	7	− 4.9	−14.1	+16.9	Too underexposed for measurement
2025	17.613	Albrecht						
2026	17.625	Albrecht	−5.4	6	+23.5		+70.2	Very much underexposed
2029	18.614	Mellor	+5.2	7			+17.8	Overexposed
2030	18.629	Mellor	−3.6	7				
2032	21.704	Mellor	−3.2	6	− 3.6			Underexposed
2033	21.727	Mellor	+3.2	7	+ 4.1	+ 8.5		
2045	22.663	Mellor	−6.3	7	+11.8	+ 4.9	+ 5.0	
2046	22.674	Mellor	+1.1	6	+11.8			Underexposed
2050	23.611	Mellor	+4.1	7				Overexposed
2051	23.622	Mellor	−0.1	7			−22.3	Overexposed
2052	23.627	Mellor	−3.6	7	+13.1			Overexposed
2058	27.687	Mellor	+8.5	7	+12.1			
2059	27.703	Mellor	+7.6	5	+19.2			
2070	29.642	Curtiss	+0.1	9	+15.9	+17.6		

TABLE 1

SINGLE-PRISM SPECTROGRAMS — CONTINUED

PLATE NO.	DATE GR. M. T.	PLATE SECURED BY	RADIAL VELOCITY REDUCED TO SUN	NO. OF LINES	VELOCITY FROM λ 4205.20	VELOCITY FROM λ 3930.65	VELOCITY FROM λ 4555.65	NOTES
	1913		km. per. sec.		km. per. sec.	km. per. sec.	km. per. sec.	
2071	June 29.668	Curtiss	+2.1	8				Overexposed
2091	July 5.677	Curtiss	+0.8	7				Overexposed
	1914							
2607	March 2.782	Mellor	−6.0	7				Overexposed
2608	2.799	Mellor	−6.9	8				
2615	9.745	Mellor	−6.8	7				Velocities mean of two measures
2616	9.778	Mellor	−8.9	6				
2645	16.710	Mellor	+0.6	8	+ 3.6	−12.7	+37.5	Velocities mean of two measures
2646	16.740	Mellor	−9.7	7	+10.1			
2693	April 13.653	Mellor	0.0	8	+18.0	+ 8.8		Velocities mean of two measures
2694	13.669	Mellor	+3.1	6	+15.1			Overexposed
2705	22.704	Mellor	−4.7	5				
2717	May 1.638	Mellor	−3.0	7				
2718	1.653	Mellor	−4.9	7				
2729	5.599	Curtiss	+1.7	7	+ 8.7			
2730	5.614	Curtiss	−1.9	7	+ 0.2			
2764	15.616	Curtiss	−3.9	7	+ 5.8	−12.1		
2765	15.635	Curtiss	+1.5	7	+18.2			
2772	17.667	Curtiss	+4.9	7	+11.9	− 8.7		
2773	17.693	Curtiss	+3.6	6				Underexposed
	1917							
3881	March 24.721	Kiess	−1.1	8	− 2.3	− 1.6		
3882	24.745	Kiess	−8.9	8	− 3.7	− 4.7		
3887	29.700	Kiess	+6.6	7		− 7.7		
3888	29.725	Kiess	−4.8	8		−12.7		
3889	29.751	Kiess	−3.6	8	+ 3.1	− 4.7		
3913	April 21.597	Kiess	+6.3	8	+ 2.9	−10.5		
3914	21.623	Kiess	−3.4	8	+ 1.5	+ 3.4		
3918	27.660	Kiess	−2.2	15	+ 8.6	− 2.9		Velocities mean of two measures
3922	May 2.647	Kiess	−3.7	16	+ 5.9	− 1.2	+18.7	Velocites mean of two measures
3926	10.637	Kiess	−0.2	14		−18.6		Velocities mean
3927	10.665	Kiess	+0.6	8		− 3.7		of two measures
3933	17.663	Kiess	−5.8	5				Too underexposed for measurement
3934	17.690	Kiess						
3940	June 8.620	Kiess	−2.5	16		− 3.2		

TABLE 2

THREE-PRISM SPECTROGRAMS

PLATE NO.	DATE	RADIAL VELOCITY REDUCED TO SUN	NO. OF LINES
		km. per sec.	
1628	1900 Jan. 22	+0.65	23
2380	1902 May 11	−0.20	20
3806	1905 May 24	−2.28	20
3838	1905 June 18	+1.09	21
5256	1908 April 30	+2.87	15

TABLE 3

KNOWN LINES MEASURED

WAVE-LENGTH	ELEMENT
3750.27	Hydrogen, H$_{\kappa}$
3770.73	Hydrogen, Hι
3798.00	Hydrogen, Hθ
3835.51	Hydrogen, Hη
3856.2	Silicon
3862.8	Silicon
3889.15	Hydrogen, Hζ
3905.7	Silicon
3933.82	Calcium, K
3968.63	Calcium, H
3970.33	Hydrogen, Hϵ
4102.00	Hydrogen, Hδ
4128.20	Silicon
4131.04	Silicon
4340.53	Hydrogen, Hγ
4481.34	Magnesium
4549.70	Iron, Titanium
4861.57	Hydrogen, Hβ

TABLE 4

VARIABLE LINES OBSERVED

GROUP I.		GROUP II.	
WAVE-LENGTH	ELEMENT	WAVE-LENGTH	ELEMENT
3788.8		3848.6	Tb 3848.90
3820.0	Eu 3819.80	3853.9	
3898.7		3939.4	Tb 3939.70
3899.1	(Eu 3898.90)	3942.4	(Tb 3942.35)
3907.3	Eu 3907.29	3944.8	(Tb 3944.35, 3945.02)
3925.3		3954.6	(Tb 3954.21)
3930.6	Eu 3930.66	3976.8	Tb 3977.00
3958.0		4000.6	
3972.0	Eu 3972.16	4033.0	Tb 4033.20
3978.6	(Eu 3978.60)	4050.5	
3982.1		4075.7	
4012.6		4077.9	
4073.5		4122.9	
4085.8	(Eu 4085.54)	4200.9	(Tb 4201.16)
4099.3		4233.3	(Tb 4232.98)
4129.7	Eu 4129.90	4262.1	
4132.7		4278.4	Tb 4278.70
4205.3	Eu 4205.20	4325.7	Tb 4326.00
4435.4	Eu 4435.75	4555.6	
4522.8	Eu 4522.76	4815.0	
4912.5	Eu 4912.61		

TABLE 5

WAVE-LENGTHS FROM SINGLE-PRISM SPECTROGRAMS

WAVE-LENGTHS	TIMES OBS'D	NOTES AND SUGGESTED IDENTIFICATIONS
3747.6	2	Tb 3747.50; Yt 3747.70
3748.2	2	
3755.6	2	Tb 3755.39
3759.5	3	La 3759.33; Ti 3759.45
3761.3	1	
3765.4	1	Tb 3765.28
3769.6	1	
3771.7	1	
3788.8	1	Dy 3788.59; Yt 3788.88
3794.8	1	La 3794.91
3806.6	1	
3807.2	2	Tb 3807.02
3809.2	1	
3812.5	1	
3814.1	1	Gd 3814.15
3816.0	3	Fe 3815.99, enhanced
3816.6	1	Dy 3816.90
3817.5	1	
3820.0	2	Eu 3819.80, variable
3826.0	1	Fe 3826.05, enhanced
3827.8	1	Fe 3827.98, enhanced
3833.2	1	Yt 3833.05
3834.2	1	Fe 3834.38
3842.4	2	Gd 3842.40; Tb 3842.62
3848.6	1	Tb 3848.90
3851.1	2	Gd 3850.85 Gd 3851.15, blend
3853.9	3	variable, blend
3857.2	1	
3858.3	1	
3860.0	2	Fe 3860.05
3861.1	1	
3863.9	1	
3865.4	2	Fe 3865.68; Eu 3865.69
3866.1	1	
3868.3	1	
3869.6	1	Tb 3869.90
3871.9	1	La 3871.80
3872.6	2	Dy 3872.28; Fe 3872.66; broad blend
3874.1	2	Tb 3873.93; Tb 3874.31
3875.8	1	

TABLE 5

WAVE-LENGTHS FROM SINGLE-PRISM SPECTROGRAMS — CONTINUED

WAVE-LENGTHS	TIMES OBS'D	NOTES AND SUGGESTED IDENTIFICATIONS
3878.2	1	Fe 3878.17
3879.1	1	
3880.6	1	
3881.3	1	
3882.7	2	
3886.8	1	La 3886.49
3887.5	1	
3892.4	1	
3895.2	2	Gd 3894.88
3897.0	2	Tb 3896.74
3898.7	3	Dy 3898.70, variable
3899.1	1	Eu 3899.08; Tb 3899.34
3900.0	1	Fe 3899.85
3900.7	2	Ti 3900.68
3901.7	1	Tb 3901.48; Tb 3901.75
3902.7	1	Gd 3902.75
3904.0	1	
3905.0	1	Ti 3904.92
3906.0	2	
3907.3	3	Eu 3907.29, variable
3908.4	2	
3913.8	2	Ti 3913.60, enhanced
3915.0	1	Dy 3915.00
3916.7	1	Gd 3916.70
3918.6	1	
3922.1	1	
3923.3	2	Dy 3923.49
3925.3	1	Tb 3925.58
3928.0	1	
3929.5	1	La 3929.36
3930.6	12	Eu 3930.66, variable
3931.9	1	Dy 3931.66
3935.1	1	Gd 3934.97; Tb 3935.38
3936.3	2	
3938.6	3	
3939.4	1	Tb 3939.70
3940.7	1	
3942.4	3	Tb 3942.35; Dy 3942.65, variable
3944.8	2	Dy 3944.83; Tb 3945.02, variable
3945.6	1	

TABLE 5

WAVE-LENGTHS FROM SINGLE-PRISM SPECTROGRAMS — CONTINUED

WAVE-LENGTHS	TIMES OBS'D	NOTES AND SUGGESTED IDENTIFICATIONS
3950.6	1	Yt 3950.50; Dy 3950.52
3954.6	1	Tb 3954.21; Dy 3954.68
3958.0	2	Gd 3957.84; Dy 3957.93; Tb 3958.11, broad blend, variable
3959.6	1	Gd 3959.67
3963.2	1	
3965.0	1	Eu 3965.06
3969.7	1	Fe 3969.41
3970.3	8	
3971.1	1	
3972.0	4	Eu 3972.16, variable
3974.9	2	
3976.8	2	Tb 3977.00, variable
3977.3	1	
3978.6	1	Eu 3978.60; Dy 3978.71
3982.1	3	Tb 3982.04; Dy 3982.09, variable
3984.0	3	Dy 3983.81; Fe 3984.13; Dy 3984.37, broad blend
3986.3	1	
3991.6	2	Dy 3991.48
3996.4	1	Gd 3996.50; Dy 3996.84
3999.0	1	Ti 3999.00
4000.6	2	Dy 4000.62, variable
4002.8	1	Tb 4002.73
4005.3	2	Fe 4005.41; Tb 4005.65
4009.0	1	
4012.6	26	Tb 4012.99; Eu 4012.99, variable
4013.1	1	
4024.8	4	Dy 4024.58; Ti 4024.71
4028.4	4	Ti 4028.50, enhanced
4030.4	1	
4033.0	4	Ga 4033.18; Tb 4033.20, variable
4034.1	1	
4034.4	1	
4036.4	1	Dy 4036.48
4038.1	2	Gd 4038.06
4045.5	1	
4046.6	1	
4049.0	5	
4050.5	2	La 4050.24; Dy 4050.73, variable
4054.0	5	
4055.4	1	

TABLE 5

WAVE-LENGTHS FROM SINGLE-PRISM SPECTROGRAMS — CONTINUED

WAVE-LENGTHS	TIMES OBS'D.	NOTES AND SUGGESTED IDENTIFICATIONS
4062.0	3	Tb 4061.74
4063.6	2	Gd 4063.62
4065.3	1	
4070.5	5	Gd 4070.50
4071.9	1	Fe 4071.90, enhanced
4073.5	4	Dy 4073.29; Gd 4073.40; Gd 4073.97, broad blend, variable
4075.7	8	variable
4077.9	3	Yt 4077.52; Dy 4078.12, variable
4082.7	1	
4085.8	1	Eu 4085.54; Gd 4085.74
4087.4	1	
4093.7	1	
4099.3	1	
4100.4	1	
4103.4	1	Dy 4103.47
4110.5	2	
4117.5	1	
4119.5	1	Dy 4119.45
4122.9	4	variable
4125.2	1	Yt 4125.10
4129.2	2	
4129.7	7	Eu 4129.90, variable
4132.7	8	variable
4146.4	1	Dy 4146.22
4161.6	3	
4163.8	2	Ti 4163.81, enhanced
4166.9	2	
4172.2	5	Ti 4172.07, enhanced; Ga 4172.21
4173.8	8	
4177.7	3	Yt 4177.69; Fe 4177.76
4179.3	6	
4184.7	4	Gd 4184.48
4187.4	2	La 4187.47
4191.0	1	
4196.1	2	
4198.4	1	Fe 4198.47
4200.9	11	Tb 4201.16, variable
4205.3	11	Eu 4205.20, variable
4207.9	1	
4215.6	3	

TABLE 5

WAVE-LENGTHS FROM SINGLE-PRISM SPECTROGRAMS — CONTINUED

WAVE-LENGTHS	TIMES OBS'D	NOTES AND SUGGESTED IDENTIFICATIONS.
4230.1	1	
4233.3		Tb 4233.00; Fe 4233.33, enhanced, variable
4236.1	2	Yt 4235.89; Yt 4236.10; Fe 4236.11
4239.6	1	Tb 4239.44
4242.5	1	Tb 4242.73
4256.2	2	
4258.2	2	Tb 4258.38
4262.1	5	variable
4275.8	1	
4278.4	1	
4288.2	1	
4290.2	3	Ti 4290.39, enhanced
4296.8	11	
4300.2	6	Ti 4300.21
4303.4	6	
4312.7	1	
4314.9	3	Ti 4314.96; Fe 4315.25
4325.7	8	Gd 4325.81, variable
4330.5	2	
4336.0	1	
4337.4	2	Fe 4337.20
4338.3	2	Ti 4338.08, enhanced
4341.5	1	Gd 4341.45
4342.4	1	Gd 4342.37; Tb 4342.70
4351.0	6	Cr 4351.93
4357.6	1	
4363.0	1	
4363.8	1	
4391.2	1	
4395.6	1	
4435.5	4	Eu 4435.75, variable
4448.2	1	Tb 4448.21
4451.5	1	
4455.0	1	La 4455.97; Mn 4455.99
4461.9	2	Fe 4461.82
4489.2	3	Ti 4489.25
4490.9	2	
4493.7	2	
4501.2	1	Ti 4501.44, enhanced
4508.3	1	Fe 4508.44, enhanced

TABLE 5

WAVE-LENGTHS FROM SINGLE-PRISM SPECTROGRAMS — CONTINUED

WAVE-LENGTHS	TIMES OBS'D	NOTES AND SUGGESTED IDENTIFICATIONS
4515.5	5	
4520.5	3	
4522.8	5	Eu 4522.76, variable
4534.0	7	Ti 4534.14
4545.5	1	
4547.0	1	
4555.6	11	blend, variable
4558.8	6	Cr 4558.82, enhanced
4564.2	1	Ti 4563.94, enhanced
4571.9	1	Ti 4572.16, enhanced
4576.5	1	
4577.8	1	Dy 4578.00
4583.9	8	Fe 4584.01
4621.8	1	
4629.3	1	
4815.0	1	variable
4819.3	1	
4863.8	1	
4865.0	2	
4884.6	1	
4886.8	1	
4912.5	1	Eu 4912.61, variable
4937.6	1	

TABLE 6

WAVE-LENGTHS FROM THREE-PRISM SPECTROGRAMS

PLATE 1628 WAVE-LENGTH NOTES	2380 WAVE-LENGTH NOTES	3806 WAVE-LENGTH NOTES	3838 WAVE-LENGTH NOTES	5256 WAVE-LENGTH NOTES	MEAN WAVE-LENGTH	IDENTIFICATIONS
4128.29 2b	4128.14 4				4128.22	Si 4128.20
4129.20 00					4129.20	
4129.89 1	4129.74 00				4129.82	Eu 4129.90
4131.07 5b	4131.11				4131.09	Si 4131.04
	4132.15 00				4132.15	
	4132.74 1				4132.74	
4136.45 0					4136.45	
	4143.29 1				4143.29	Dy 4143.26; Pr 4143.29
4144.72 00					4144.72	Tb 4144.60
4145.19 00	4145.31 1				4145.25	
4146.01 00bl?	4146.26 1				4146.14	Dy 4146.22
	4147.62 00				4147.62	
	4151.15 1				4151.15	
	4153.93 00				4153.93	
	4159.13 00				4159.13	
4162.02 0b bl?					4161.02	
	4163.77 00				4163.77	Ti 4163.81
4165.98 0	4165.71 00				4165.85	
	4166.99 00bl?				4166.99	
4171.08 00	4171.00 2				4171.04	
4172.30 2	4172.15 2				4177.22	Ti 4172.07; Ga 4172.21
4173.76 2	4173.72 2				4173.74	
4177.92 1	4177.77 1 bl?				4177.84	Yt 4177.69; Fe 4177.76
4179.13 1	4179.04 1				4179.08	
4179.92 0	4179.77 1				4179.84	
	4180.88 0b				4180.88	
	4182.38 0b				4182.38	Eu 4182.42
	4183.43 00				4183.43	
4184.62 1 bl?	4184.45 1				4184.54	Gd 4184.48
4185.51 0					4185.51	
	4187.13 00				4187.13	Dy 4187.00; Fe 4187.21
4187.43 0b					4187.43	
	4188.00 00				4188.00	Fe 4187.97
4190.92 1b	4191.10 0				4191.01	
	4193.33 00				4193.33	
	4194.07 00				4194.07	
4195.38 1					4195.38	
4196.48 0	4196.26 0				4196.37	
4198.40 00	4198.54 0				4198.47	Fe 4198.47
4199.64 0	4199.62 00				4199.63	

TABLE 6

WAVE-LENGTHS FROM THREE-PRISM SPECTROGRAMS — CONTINUED

PLATE 1628 WAVE-LENGTH NOTES	2380 WAVE-LENGTH NOTES	3806 WAVE-LENGTH NOTES	3838 WAVE-LENGTH NOTES	5256 WAVE-LENGTH NOTES	MEAN WAVE-LENGTH	IDENTIFICATIONS
	4200.05 1				4200.65	
4200.98 1					4200.98	
	4201.39 1				4201.39	Tb 4201.18
	4202.53 00				4202.53	
4202.96 00	4203.09 00				4203.02	
	4204.23 00				4204.23	
4205.19	4205.15 2				4205.17	Eu 4205.20
	4206.77 0				4206.77	Dy 4206.70; Pr 4206.88
	4207.83 0				4207.83	
	4210.48 0				4210.48	Fe 4210.52
	4212.06 1				4212.06	Gd 4212.18
4213.51 00b	4213.20 00				4213.20	Dy 4213.34
	4213.78				4213.78	
4214.82 0					4214.82	
4215.77 2 bl	4215.66 0b bl?				4215.72	
4217.08 00	4217.27 0				4217.18	
	4218.02 0				4218.02	
4219.52 00					4219.52	Fe 4219.52
4219.97 00					4219.97	
4222.13 00					4222.13	
	4223.09 0				4223.09	Pr 4223.16
4225.10 00b	4225.20 1				4225.15	Dy 4225.32
	4226.08 00				4226.08	Gd 4226.03
4227.60 0	4227.49 1				4227.54	Fe 4227.60
	4232.04 00				4232.04	
4233.25 3	4233.37 2				4233.31	Fe 4233.33 Enhanced
	4234.35 00				4234.35	
	4234.97 00				4234.97	
4235.44 0	4235.69 00				4235.56	
	4236.61 00				4236.61	
4238.16 00					4238.16	
4238.88 00	4239.03 00				4238.96	Fe 4238.97
4242.58 1 bl?	4242.66 1				4242.62	
	4243.75 00				4243.75	
4244.21 0b					4244.21	
	4246.59 00				4246.59	
4247.65 00	4247.57 00				4247.61	Fe 4247.59
4248.93 00					4248.93	
4250.29 0	4250.40 1				4250.35	Fe 4250.29
4250.95 0	4250.71 1				4250.83	Fe 4250.95

TABLE 6

WAVE-LENGTHS FROM THREE-PRISM SPECTROGRAMS — CONTINUED

PLATE 1628 WAVE-LENGTH NOTES	2380 WAVE-LENGTH NOTES	3806 WAVE-LENGTH NOTES	3838 WAVE-LENGTH NOTES	5256 WAVE-LENGTH NOTES	MEAN WAVE LENGTH	IDENTIFICATIONS
	4251.81 1				4251.81	Gd 4251.92
4252.79 0	4252.87 1				4252.83	
	4253.53 1				4253.53	
4254.69 1	4254.66 1				4254.68	Nh 4254 58
4256.12 1			4256.05 1b bl?		4256.09	
4257.14 00					4257.14	
4258.33 2	4258.28 1		4258.14 1		4258.25	Tb 4258.38
4259.44 00	4259.56 1		4259.45 1		4259.48	
4260.66 00	4260.66 1		4260.64 0		4260.66	Fe 4260.64
4262.04 1	4262.15 2		4261.99 1b bl?		4262.09	
4263.07 00					4263.07	
			4263.47 0		4263.47	
4264.07 1b bl?	4264.10 00		4264.01 0		4264.06	
			4268.86 1		4268.86	
4269.34 1	4269.48 1		4269.47 1		4269.43	
			4270.99 1		4270.99	
4271.92 1b bl	4272.01 1b		4272.06 1	4271.95 1	4271.99	Fe 4271.91
			4272.52 1		4272.52	Pr 4272.43
4273.49 1	4273.47 1		4273.50 1b bl?	4273.48 1b	4273.50	
			4275.00 1		4275.00	Cr 4274.96
4275.62 1	4275.80 0		4275.88 1	4275.71 1bd	4275.75	
4278.22 1	4278.42 1		4278.49 0		4278.38	
			4279.29 0		4279.29	
4280.24 00					4280.24	Pr 4280.25
	4280.68 0		4280.82 0		4280.75	Gd 4280.60
4281.06 00					4281.06	
4282.72 00		4282.75 1	4282.77 1		4282.75	Pr 4282.60; Ti 4282.88
		4283.62 0			4283.62	
4284.38 1	4284.38 1	4284.45 1	4284.66 1	4284.54 1	4284.48	
4285.58 00					4285.58	
4286.38 0			4286.66 1	4286.39 0	4286.48	
			4287.58 1		4287.58	
4288.05 0					4288.05	
4288.50 0					4288.50	
		4289.03 1			4289.03	
			4290.03 1		4290.03	
4290.24 0	4290.17 1		4290.39 1	4290.26 obl	4290.26	Ti 4290.39
	4292.93 0		4292.67 1		4292.80	
4293.10 00		4293.39 0	4293.14 1		4293.21	
4294.34 00	4294.22 00	4294.20 1	4294.24 1	4294.28 1	4294.26	Fe 4294.26; Ti 4294.29

TABLE 6

WAVE-LENGTHS FROM THREE-PRISM SPECTROGRAMS — CONTINUED

PLATE 1628 WAVE-LENGTH NOTES	2380 WAVE-LENGTH NOTES	3806 WAVE-LENGTH NOTES	3838 WAVE-LENGTH NOTES	5256 WAVE-LENGTH NOTES	MEAN WAVE-LENGTH	IDENTIFICATIONS
4295.24 0		4295.07 0			4295.15	Dy 4295.18
				4295.48 00	4295.48	
4296.72 2	4296.81 1	4296.77 1b bl?	4296.70 1b bl?	4296.60 1b	4296.72	
			4298.75 1		4298.75	
4299.41 00	4299.20 00	4299.31 1	4299.43 1		4299.34	Fe 4299.42
4300.11 0	4300.24 1	4300.31 1	4300.30 1	4300.16 0	4300.22	Ti 4300.21
		4300.63 1			4300.63	
4302.03 1	4302.04 1	4301.98 1b bl?	4302.01 1b bl?	4301.85 0	4300.98	
4303.34 2	4303.51 1	4303.33 1b bl?	4303.30 1	4303.26 2	4303.35	
			4303.62 1		4303.62	
		4304.23 1			4304.23	
		4305.65 1		4305.58 1	4305.62	
		4306.24 1	4306.15 1		4306.20	Ti 4306.07
	4306.97 0		4307.03 1		4307.00	
4308.06 1	4308.00 1	4308.06 1	4308.09 1	4308.01 1	4308.04	Ti 4308.04; Fe 4308.08
	4309.02 00				4309.02	Tb 4308.85
4310.00 00	4309.99 00	3409.88 0	4309.86 1	4310.06 1	4309.96	
		4310.72 1	4310.55 1		4310.64	
			4311.29 1		4311.29	
		4311.74 1			4311.74	
		4312 20 1			4312.20	
4313.11 2	4313.09 1	4313.05 1	4313.04 1	4313.05 0	4313.07	Ti 4313.04
		4313.81 0			4313.81	
4314.39 1		4314.56 1	4314.46 0	4314.27 0	4314.42	
4315.27 1	4315.10 00	4315.32 1bl?	4315.05 1	4315.12 1	4315.17	Fe 4315.25; Ti 4314.96
4317.10 0			4316.99 0		4317.05	
4317.92 00		4317.69 1			4317.80	
		4318.56 1			4318.56	
4319.69 ob			4319.81 1	4319.72 0	4319.74	
4321.10 obl?		4321.03 1			4321.06	
	4321.32 ob				4321.32	
		4321.75 1			4321.75	
4324.02 00			4324.04 1	4323.82 0	4323.96	
		4324.47 1bl		4324.69 0	4324.58	
		4325.18 1	4324.93 1		4325.05	Gd 4325.18
4325.73 1	4325.63 1	4325.89 1b	4325.73 1b bl?	4325.52 1	4325.70	Gd 4325.81
	4326.17 0				4326.17	Tb 4326.00
			4326.79 0		4326.79	Tb 4326.64
		4327.78 0	4327.49 0		4327.64	
			4328.08 0		4328.08	

TABLE 6

WAVE-LENGTHS FROM THREE-PRISM SPECTROGRAMS — CONTINUED

PLATE 1628 WAVE-LENGTH NOTES	2380 WAVE-LENGTH NOTES	3806 WAVE-LENGTH NOTES	3838 WAVE-LENGTH NOTES	5256 WAVE-LENGTH NOTES	MEAN WAVE-LENGTH	IDENTIFICATIONS
		4328.53 0			4328.53	
	4329.05 00	4329.09 0			4329.07	Sm 4329.19
4329.51 00			4329.31 1		4329.41	
4330.50 00	4330.49 0		4330.61 1b bl?		4330.53	
			4332.84 0		4332.84	
		4333.23 0			4333.23	
		4333.96 0			4333.96	La 4333.93; Pr 4334.10
			4337.13 1b		4337.13	
4337.95 0	4338.02 ob		4338.20 1		4338.07	Ti 4338.08
4339.19 00					4339.19	
4340.55 8	4340.60 8		4340.65 8	4340.72 8b	4340.63	Hγ 4340.53
4341.72 1					4341.72	
	4344.19 ob				4344.19	
			4346.78 1		4346.78	
			4349.93 0		4349.93	
			4350.04 0		4350.04	
			4350.83 0		4350.83	Nh 4350.89
4351.84 1	4351.96 2	4351.91 1b	4351.88 1b bl?	4351.82 2	4351.88	Cr 4351.93
		4352.81 1	4352.75 1		4352.78	
		4354.41 1	4354.32 1	4354.54 0	4354.42	La 4354.56
	4355.46 00	4355.74 0	4355.74 0		4355.65	
		4356.84 1	4356.70 1		4356.77	Nh 4356.87
4357.68 1		4357.89 1bl?	4357.68 1	4357.59 0	4357.71	
		4359.70 1bl?			4359.70	
		4361.42 1bl?	4361.29 0	4361.57 od	4361.43	
				4363.02 od	4363.02	
4363.56 00					4363.56	
		4365.95 1			4365.95	
		4367.10 0			4367.10	
		4368.44 1bl?			4368.44	Pr 4368.50
4369.60 0	4369.58 1	4369.73 1b bl?	4369.65 1	4369.45 0	4369.60	
			4370.79 0	4370.46 0	4370.62	
			4371.31 1		4371.31	
4372.17 00					4372.17	
4375.00 0		4375.29 1b	4375.21 1b		4375.17	Yt 4375.11
			4376.32 0		4376.32	
4377.38 00	4377.21 00		4377.24 1	4377.18 1	4377.25	
				4378.53 0	4378.53	
		4381.68 1			4381.68	
4382.08 0					4382.08	

TABLE 6
WAVE-LENGTHS FROM THREE-PRISM SPECTROGRAMS — CONTINUED

PLATE 1628 WAVE-LENGTH NOTES	2380 WAVE-LENGTH NOTES	3806 WAVE-LENGTH NOTES	3838 WAVE-LENGTH NOTES	5256 WAVE-LENGTH NOTES	MEAN WAVE-LENGTH	IDENTIFICATIONS
		4382.39 0	4382.53 0		4382.46	
4383.58 0		4383.71 1	4383.48 1		4383.59	La 4383.62; Fe 4383.72
4384.21 1	4384.29 00	4384.48 1bl?	4384.42 1b bl?	4384.12 1	4384.30	
4385.55 1	4385.57 1	4385.55 1b	4385.50 1b bl?	4385.53 1	4385.54	
4386.74 00	4387.09 0	4386.97	4386.98 1	4386.70 0	4386.90	
		4388.04 1	4388.17 1		4388.10	
			4388.39 1		4388.39	
		4389.61 1			4389.61	
				4390.46 1	4390.46	
4391.98 00				4391.89 0	4391.93	
			4393.04 0		4393.04	
			4393.97 0		4393.97	
4395.26 0	4395.00 0	4395.14 1	4395.13 1	4395.08 0	4395.12	Dy 4395.12; Ti 4395.21
4395.92 0			4396.01 0	4395.84 0	4395.92	
4398.30 0					4398.30	Yt 4398.20
4399.68 0b	4399.95 00	4399.90 0	4399.83 1		4399.84	Ti 4399.94
4401.44 0				4401.69 0	4401.56	Sc 4401.59
4403.03 1b	4403.06 0	4403.01 1	4402.97 1	4403.16 0b	4403.05	
4404.94 1	4404.85 1	4404.88 1b bl	4404.91 1b bl?	4404.73 0b	4404.86	Fe 4404.92
4406.77 00		4406.80 1	4406.91 0		4406.83	Gd 4406.85
		4408.06 0	4407.95 0		4408.00	
		4409.53 1			4409.53	Dy 4409.57
	4409.93 0		4410.12 0		4410.02	
			4411.15 1		4411.15	
				4412.41 0	4412.41	
4413.79 1	4414.05 0b bl?	4413.80 1		4414.02 0	4413.92	Pr 4413.93
			4414.60 1		4414.60	
4415.10 00		4415.32 1bl?			4415.21	
4417.04 2	4417.18 00	4417.07 2	4416.81 1b bl?	4416.83 2	4416.99	
		4417.93 1	4417.86 1		4417.90	Ti 4417.88
	4419.24 00	4419.05 1			4419.14	Gd 4419.21
4419.52 00bl					4419.52	
		4419.99 1			4419.99	
			4422.13 1		4422.13	
		4422.01 0			4422.01	Yt 4422.77
		4426.08 0			4426.08	
		4427.35 1bl?			4247.35	
		4428.49 1b bl			4428.49	
				4431.67 00	4431.67	
4433.88 00				4433.88 00	4433.88	

TABLE 6

WAVE-LENGTHS FROM THREE-PRISM SPECTROGRAMS — CONTINUED

PLATE 1628 WAVE-LENGTH NOTES	2380 WAVE-LENGTH NOTES	3806 WAVE-LENGTH NOTES	3838 WAVE-LENGTH NOTES	5256 WAVE-LENGTH NOTES	MEAN WAVE-LENGTH	IDENTIFICATIONS
	4434.25 00		4434.38 1		4434.32	
	4435.60 0				4435.60	Eu 4435.75
	4436.74 00				4436.74	
	4438.06 00	4438.13 0			4438.10	
4444.67 0					4444.67	
			4446.21 1	4446.29 0	4446.25	
	4447.81 0b		4447.79 1		4447.80	
4450.55 obl?		4450.69 1bl?	4450.59 1		4450.61	
4451.78 0		4451.84 1b		4451.66 1	4451.76	Nd 4451.73; Mn 4451.75
		4453.38 1bl?	4453.35 1	4453.32 1	4453.35	
		4454.48 1			4454.48	
4455.34 0	4455.36 0	4455.37 2		4455.41 0	4455.37	
4457.18 00					4457.18	
	4458.49 00				4458.49	
				4460.11 0	4460.11	
		4461.37 1		4461.45 1	4461.41	
4461.84 1	4461.75 0	4461.98 1			4461.86	Fe 4461.82
			4463.31 1		4463.31	
4464.84 00	4464.47 0	4464.55 1	4464.59 1		4464.54	
		4465.34 0			4465.34	
		4465.83 1			4465.83	
		4468.07 0			4468.07	
4468.72 0		4468.62 1			4468.67	Ti 4468.66
4471.14 00	4471.42 0b	4471.38 0b bl?	4471.15 0	4471.30 0	4471.28	
4473.07 0	4473.08 1	4473.17 1b bl?		4472.96 1	4473.07	Mn 4472.97
		4474.35 0			4474.35	
4476.22 0					4476.22	Fe 4476.20
			4478.00 0		4478.00	
			4478.87 1		4478.87	Gd 4478.97
4481.31 2	4481.28 2	4481.30 3	4481.33 2	4481.38 2	4481.32	Mg 4481.34
		4484.07 0			4484.07	
4485.48 0obl?					4485.48	
4487.30 00					4487.30	
4489.35 1	4489.39 00	4489.31 1b bl?	4489.23 1	4489.39 1	4489.33	Ti 4489.25
		4490.62 1b bl?			4490.62	
4491.46 obl?	4491.68 0		4491.51 1	4491.40 1	4491.51	
4493.70 0			4493.58 1	4493.59 0	4493.62	
			4494.83 1		4494.83	Fe 4494.74
			4497.23 0		4497.23	
4499.89 0		4500.02 0			4499.96	

TABLE 6

WAVE-LENGTHS FROM THREE-PRISM SPECTROGRAMS — CONTINUED

PLATE 1628 WAVE-LENGTH NOTES	2380 WAVE-LENGTH NOTES	3806 WAVE-LENGTH NOTES	3838 WAVE-LENGTH NOTES	5256 WAVE-LENGTH NOTES	MLAN WAVE-LENGTH	IDENTIFICATIONS
4501.43 00	4501.32 0	4501.43 1	4501.37 1	4501.43 1	4501.40	Ti 4501.44
	4503.02 0		4503.23 1d		4503.12	
			4504.95 1d		4504.95	
4506.66 00					4506.66	
	4507.03 00	4507.23 0		4506.93 1	4507.06	
4508.52 1	4508.62 1	4508.52 1	4508.36 1	4508.51 1	4508.51	Fe 4508.44, enhanced
		4509.60 0			4509.60	
			4510.47 1b bl?	4510.40 0b	4510.44	Pr. 4510.32
4512.08 00				4511.95 0b	4512.01	
4514.37 00	4514.18 1	4514.18 1	4514.31 2	4514.21 1	4514.25	
		4514.52 1			4514.52	
4515.64 1	4515.88 1	4515.62 1b	4515.66 2	4515.58 1	4515.67	
		4518.30 0			4518.30	Ti 4518.20
4520.58 1	4520.66 1	4520.44 1b	4520.21 1b	4520.15 1	4520.41	
4522.93 1	4522.92 1	4522.90 0b	4522.79 1	4522.75 1	4522.86	Eu 4522.76; Ti 4522.97
4525.09 00			4524.97 1		4525.03	
		4526.67 0		4526.76 0	4526.72	Cr 4526.63
		4527.74 0			4527.74	
		4528.74 1		4528.54 0	4528.64	
				4529.74 0	4529.74	
			4533.45 0		4533.45	Ti 4533.42
4534.27 0	4534.28 1	4534.32 2	4534.22 1	4534.11 2	4534.24	Ti 4534.14; Pr 4534.32
4539.68 0	4539.87 00	4539.82 2b		4539.73 1	4539.78	
4541.67 1		4541.72 2	4541.60 0b	4541.54 1	4541.63	
4544.06 00		4543.70 0			4543.88	
		4544.97 0			4544.97	
4549.64 3	4549.61 3	4549.59 3	4549.63 3	4549.50 3	4549.59	Fe 4549.64, enhanced
4551.51 00					4551.51	
		4555.09 0	4554.93 0	4554.98 1	4555.00	Cr 4555.15
4555.71 1b		4556.18 1b	4555.94 0	4555.97 1	4555.95	
						[La 4558.62
4558.93 1	4558.96 0	4558.78 1b	4558.73 2	4558.62 2	4558.80	Cr 4558.82; Enhanced;
		4560.08 0			4560.08	
			4561.39 0		4561.39	
4564.14 0		4563.90 0		4563.83 0	4563.96	Ti 4563.94; Tb 4563.87
4565.82 0		4565.90 1	4565.71 0	4565.80 0	4565.81	Co 4565.80
		4569.59 1			4569.59	
		4570.37 0			4570.37	
		4572.27 0	4572.04 1	4572.18 0	4572.16	Ti 4572.16
4572.69 0b bl?	4572.62 0b	4572.96 0			4572.76	
4576.54 0		4576.59 1	4576.28 1b bl?	4576.331	4576.44	

TABLE 6

WAVE-LENGTHS FROM THREE-PRISM SPECTROGRAMS — CONTINUED

PLATE 1628 WAVE-LENGTH NOTES	2380 WAVE-LENGTH NOTES	3806 WAVE-LENGTH NOTES	3838 WAVE-LENGTH NOTES	5256 WAVE LENGTH NOTES	MEAN WAVE-LENGTH	IDENTIFICATIONS
		4578.22 0			4578.22	Dy 4578.00
4579.75 1				4579.88 00bl?	4579.82	
		4580.03 1	4580.15 1b bl?		4580.09	
		4581.24 1			4581.24	
4582.86 1		4582.92 1	4582.77 1	4583.04 1	4582.90	
4584.18 1	4584.18 0b	4584.13 0b	4584.21 1	4584.03 2	4584.15	Fe 4584.01
		4587.31 0			4587.31	
4588.50 1		4588.33 1	4588.19 1	4588.32 1	4588.34	Cr 4588.38, enhanced
4590.44 1		4590.02 0	4590.13 0		4590.20	
4592.40 1		4592.21 1	4592.18 0	4592.11 1	4592.22	
		4594.14 1b bl?	4593.86 0		4594.00	Eu 4594.27
		4596.16 1b bl?		4596.08 1	4596.12	
		4598.60 1b bl?	4598.31 1	4598.36 1	4598.42	
		4611.10 0			4611.10	
		4616.73 1	4616.78 1	4616.61 1	4616.71	
		4617.64 1			4617.64	
		4618.94 1bl?	4619.09 1b bl	4618.93 1	4618.99	Cr 4619.03, enhanced
		4620.56 1	4620.63 0		4620.59	
4621.83 1		4621.90 1b bl?	4621.81 0bl?	4621.55 1bd	4621.77	
		4623.37 1			4623.37	
		4629.45 2	4629.45 1	4629.23 1	4629.38	
		4630.53 0	4630.57 0		4630.55	
		4631.78 0			4631.78	
		4634.19 1	4634.20 1	4634.10 1	4634.16	
		4635.50 1	4635.43 0	4635.45 1	4635.46	
		4638.17 0			4638.17	
		4641.01 0	4640.99 0	4640.99 0	4641.00	
		4643.45 0			4643.45	
		4653.14 0bl			4653.14	
		4654.82 0bl			4654.82	
		4657.05 1		4656.97 0	4657.01	
		4658.53 0			4658.53	Yt 4658.48
		4660.96 1			4660.96	
			4667.02 2		4667.02	
		4670.49 0b			4670.49	
		4673.53 0b		4673.63 1	4673.58	
		4681.99 1			4681.99	
			4695.63 1		4695.63	
		4697.84 1	4697.77 1		4697.80	
		4699.33 0			4699.33	

TABLE 6

WAVE-LENGTHS FROM THREE PRISM SPECTROGRAMS — CONTINUED

PLATE 1628 WAVE-LENGTH NOTES	2380 WAVE-LENGTH NOTES	3806 WAVE-LENGTH NOTES	3838 WAVE-LENGTH NOTES	5256 WAVE-LENGTH NOTES	MEAN WAVE-LENGTH	IDENTIFICATIONS
		4708.88 o			4708.88	
		4713.72 ob	4713.80 1		4713.76	
		4715.27 ob	4715.22 1		4715.24	
		4717.55 o			4717.55	
			4719.72 o		4719.72	
			4721.69 o		4721.69	
			4723.60 o		4723.60	
				4731.76 o	4731.76	
		4735.66 o			4735.66	
		4737.28 o			4737.28	
			4755.83 o		4755.83	
			4757.70 1		4757.70	
				4766.23 o	4766.23	
				4768.55 o	4768.55	
			4783.15 1b bl		4783.15	
			4784.88 1		4784.88	
			4786.52 1		4786.52	
		4800.07 ob			4800.07	
		4802.44 ob			4802.44	
		4805.14 1		4805.63 o	4805.38	
		4812.64 ob			4812.64	
			4824.27 1		4824.27	
				4845.70 1	4845.70	
		4848.36 o		4848.11 1	4848.24	
			4861.88 8	4861.57 6bd	4861.72	Hβ 4861.57

SOME RADIAL VELOCITIES OF THE COMPANION TO ALPHA CANUM VENATICORUM

By C. C. KIESS

During the period in which α Canum Venaticorum was being observed, a number of spectrograms of the companion star was secured. These were measured and reduced together with the observations of the brighter star. The results obtained are given in the following table:

The spectrum is classified as Ap, but the faint lines which appear are not of the same origin as those in the spectrum of the brighter star. Many of the faint lines agree in position with lines in the solar spectrum.

RADIAL VELOCITIES OF THE COMPANION TO ALPHA CANUM VENATICORUM

PLATE NO.	DATE, G. M. T.	OBSERVER	VEL. TO SUN	NO. LINES	NOTES
1930	1913 June 2.716	Mellor	0.0	14	Underexposed
1949	June 4.736	Mellor	− 6.2	30	
1972	June 10.679	Albrecht	− 8.6	5	Underexposed
2646	1914 March 16.772	Mellor	−13.4	15	
3883	1917 March 24.774	Kiess	+ 1.2	11	Underexposed
3928	May 10.699	Kiess	+ 2.5	13	

The mean of the six velocities is −4.1 km.

Washington, D. C.
June 12, 1919.

SPECTROGRAPHIC OBSERVATIONS OF THE VARIABLE STAR RT AURIGÆ

BY C. C. KIESS

The star RT Aurigæ (R.A. 6^h $23^m.0$; Decl. $+30°$ $33'$) is a variable of the Delta Cephei type. Its variability in brightness was discovered in 1905 by Astbury[1], who, with others, observed it sufficiently during the years 1905–07 to determine the type and period of variation. Other photometric observations have been made by von Zeipel[2], by Wendell[3], and by Kiess[4]. The period of variation is 3.72806 days.

From a series of spectrographic observations made at the Lick Observatory, Duncan[5] has shown that the radial velocity of the star is variable in a period identical with the light period. Assuming the star to be a spectroscopic binary, he has derived orbital elements which satisfy very closely the observed velocities. More recently Shapley[6] has stated that the star is a *spectrum variable*, its spectrum varying continuously in type from Class A7 at maximum to G0 at minimum.

In the autumn of 1916 the star was placed on the program for observation with the one-prism spectrograph of the Detroit Observatory. A number of reasons made it desirable that a new series of observations be obtained. The problems which it was hoped to solve were the following: 1. To determine whether the radial velocity curve exhibits secondary oscillations analogous to those in the photographic light-curve[7]; 2. To find out whether perturbations have brought about changes in the orbital elements, assuming the star to be a binary; and 3. To study the changes in spectral type with higher dispersion than that used at Mount Wilson.

The observations on which the present discussion is based are recorded in the accompanying table. The column headings are self-explanatory. The phases entered in the third column are derived from the following elements[8] for the light variation:

Heliocentric Maximum =
J. D. 2417173.459 + $3^d.72806$ E, G. M. T.

Unfortunately, cloudy weather made it impossible to secure the number of observations desired, especially at the time of maximum and minimum phases. And many of the plates which have been secured are underexposed because the exposure times were cut short by clouds.

All the observations were secured and reduced by the writer. They were made on Seed 27 plates. The spark spectrum of titanium was used as the reference spectrum. Since the star's spectrum is approximately of solar type, a reduction table was used which was derived from spectrograms of the moon made on January 7, 1917. At that time the moon's radial velocity was −0.07 km. per second.

Preliminary elements for the orbit were derived from the plotted observations by the method of Lehmann-Filhés[9]. A representation of the observations with these elements yielded the residuals given in the seventh column of the table $(O - C_1)$. These residuals were then used to derive corrections to the elements by the method of least squares, using the convenient formulæ given by Schlesinger[10]. The residuals furnished by the corrected elements are given in column eight of the table, $(O - C_2)$. For the second set of residuals we have $[vv] = 287.4$ as compared with $[vv] = 346.2$ for the first set. The probable error of a single observation is ±2.29 km. The

[1] *Journal British Astronomical Association*, Vol. 15, p. 244; 1905.
[2] *Astronomische Nachrichten*, Bd. 177, col. 371; 1908.
[3] *Annals Harvard College Observatory*, Vol. 69, p. 123.
[4] *Lick Observatory Bulletin*, Vol. 2, p. 99; 1915.
[5] *Lick Observatory Bulletin*, Vol. 5, pp. 81, 120; 1908.
[6] *Astrophysical Journal*, Vol. 45, p. 273; 1916.
[7] *Lick Observatory Bulletin*, Vol. 2, p. 108; 1915.
[8] *Lick Observatory Bulletin*, Vol. 2, p. 103; 1915.
[9] *Astronomische Nachrichten*, Bd. 136, col. 17; 1894.
[10] *Publications of the Allegheny Observatory*, Vol. 1 p. 33; 1908.

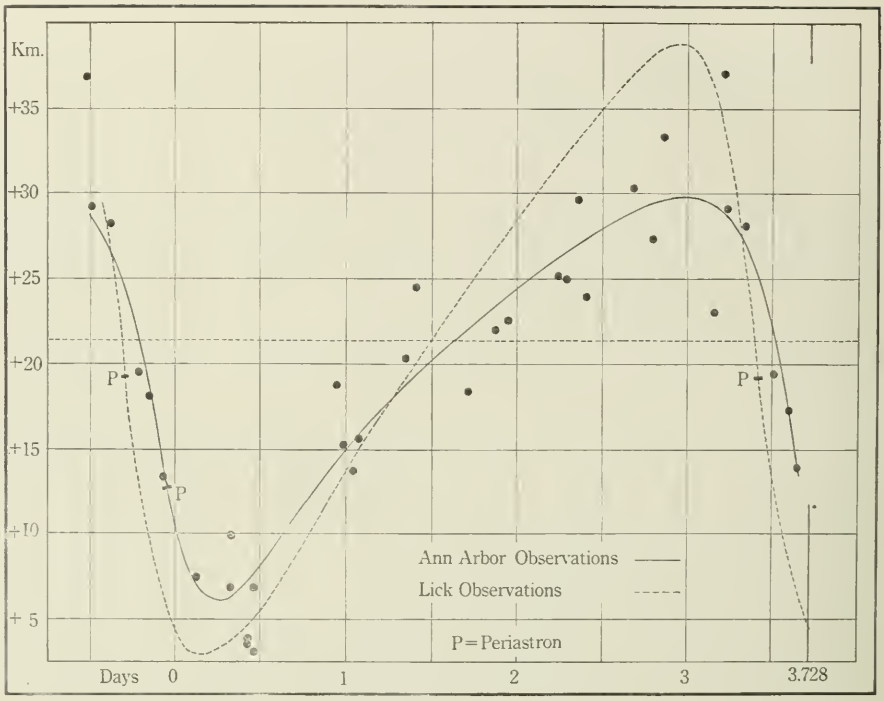


FIG. V. VELOCITY CURVES OF RT AURIGÆ

adopted elements together with those found by Duncan from his Lick Observatory spectrograms are as follows:

	LICK OBSERVATIONS.[11]	ANN ARBOR OBSERVATIONS.
P	= 3.7282 days.	3.72806 days,
T	= 3.423 ± 0.020 days,	3.686 ± 0.031 days,
ω	= 95°.016 ± 2°.502,	115°.30 ± 7°.45,
e	= 0.368 ± 0.014.	0.428 ± 0.018,
γ	= +21.434 ± 0.390 km. per sec.	+ 19.96 km. per sec.
K	= 17.902 ± 0.246 km.,	11.97 ± 1.46 km.,
$a \sin i$	= 856,500 km.,	554,700 km.
T	= Interval from maximum light to periastron.	

A comparison of the two sets of elements derived from series of observations made about nine years apart, shows differences which suggest that perturbing influences may be operative in the system. Before this question can be satisfactorily answered, however, it is desirable that definitive sets of elements based on extensive series of observations be found at stated epochs. The accompanying figure shows the curves calculated from the above sets of elements. The full-line curve is the one corresponding to the

[11] *Lick Observatory Bulletin*, Vol 5, p. 121; 1909.

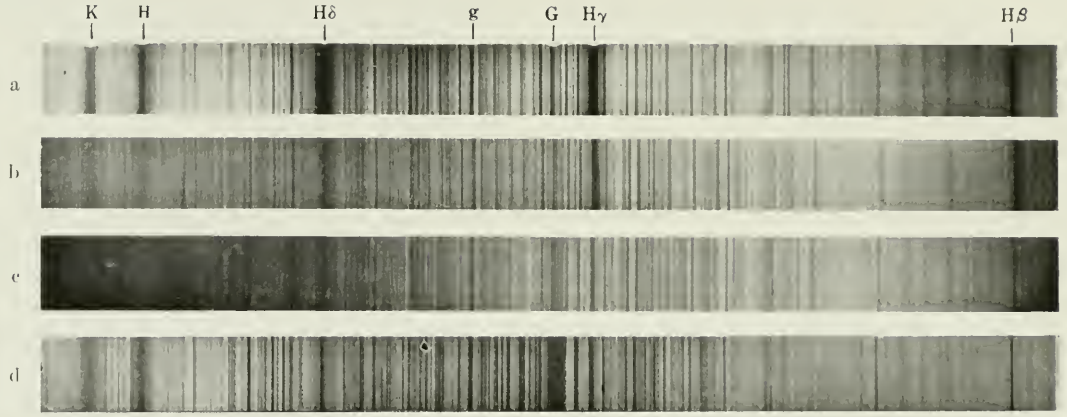


PLATE E

a. ζ LEONIS, CLASS F0

b. RT AURIGÆ, MAXIMUM, 1916, OCTOBER 6

c. RT AURIGÆ, MINIMUM, 1916, NOVEMBER 11

d. MOON. CLASS G0

Ann Arbor elements, and the dotted curve to the Lick elements. Both curves show that the maximum velocity of approach is not exactly coincident with the light maximum, but follows it by about 0.25 day.

The extent to which changes in the spectrum take place may be studied in the accompanying illustration, Plate E. Here two enlarged spectrograms of RT Aurigæ, one taken at maximum light, on 1916 October 6.772, and the other at minimum light, on 1916 November 11.764, are placed between two reference spectra, the upper one of Zeta Leonis, of Class Fo, and the lower one of the moon, of Class Go. It is seen that the hydrogen lines are more intense when the star is at maximum than when at minimum, but they

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PLATE NO.	DATE, G.M.T.	PHASE	RED. TO SUN	VEL. TO SUN	NO. OF LINES	O − C_1	O − C_2
	1916	d	km.	km.		km.	km.
3710	Sept. 29.809	0.422	+29.7	+ 3.8	23	−0.7	−3.4
3711	Sept. 29.855	0.468	+29.7	+ 3.1	26	−1.8	−4.7
3714	Sept. 30.736	1.349	+29.7	+20.3	12	+2.0	+1.6
3715	Sept. 30.804	1.417	+29.7	+24.5	29	+5.3	+5.2
3734	Oct. 6.716	3.601	+29.4	+17.3*	8	−2.7	+0.1
3735	Oct. 6.772	3.656	+29.4	+14.0	23	−3.5	−0.2
3747	Oct. 13.739	3.168	+28.6	+23.1*	6	−6.8	−6.2
3748	Oct. 13.793	3.222	+28.6	+37.1*	25	+7.6	+8.3
3749	Oct. 14.762	0.463	+28.5	+ 6.9	3	+2.1	−0.9
3762	Oct. 22.792	1.036	+27.0	+13.7	18	−0.1	−1.7
3763	Oct. 22.833	1.077	+27.0	+15.6	25	+1.2	−0.2
3787	Nov. 9.727	0.331	+21.9	+ 6.9	15	+2.5	+0.6
3794	Nov. 11.764	2.368	+21.1	+29.7	28	+1.4	+2.8
3795	Nov. 11.812	2.416	+21.1	+24.0	16	−4.7	−3.2
3803	Nov. 18.730	1.878	+18.5	+22.0	11	−2.3	−1.3
3804	Nov. 18.779	1.928	+18.4	+22.6	11	−2.2	−1.1
3812	Nov. 24.735	0.425	+15.9	+ 3.5	15	−1.0	−3.8
3820	Dec. 14.673	1.725	+ 6.3	+18.3*	8	−4.4	−3.8
	1917						
3833	Jan. 7.554	3.237	− 6.0	+29.2	23	−0.1	+0.5
3842	Jan. 14.578	2.805	− 9.7	+27.4	8	−3.1	−1.9
3843	Jan. 14.635	2.863	− 9.8	+33.4	20	+2.7	+3.9
3847	Feb. 1.660	2.247	−18.2	+25.2	13	−2.3	−0.9
3848	Feb. 1.720	2.308	−18.3	+25.0	14	−2.9	−1.5
3849	Feb. 17.673	3.348	−24.1	+28.2	26	+0.6	+1.4
3856	Mar. 1.568	0.330	−27.0	+ 9.0	36	+5.5	+3.7
3866	Mar. 12.543	0.121	−28.8	+ 7.4	14	−1.4	+0.5
3875	Mar. 22.560	2.682	−29.7	+30.3	7	+0.2	+1.5
3876	Mar. 24.557	0.051	−29.7	+18.7	34	+6.2	+4.4
3877	Mar. 24.593	0.988	−29.8	+15.2	48	+2.2	+0.4
3893	Apr. 3.579	3.517	−29.4	+19.5	30	−3.7	−1.8

* Mean of two measures.

do not equal in intensity the corresponding lines in Zeta Leonis. At no time during the variation do the lines constituting the G-band appear blended as in the solar spectrum, but present an appearance intermediate between that of an F-type and a G-type spectrum. The only calcium line admitting of comparison is the g line. It is more intense when the variable is at minimum than when at maximum. Other lines, usually groups of faint lines, seen separate at maximum appear to blend at minimum. Although variations in the intensity of the lines are seen to exist, the range does not seem to be as great as that found at Mount Wilson.

Ann Arbor, Michigan,
June 15, 1917.

PHOTOGRAPHIC DETERMINATION OF THE POSITIONS OF STARS AND NEBULOUS KNOTS IN THE REGION OF THE GREAT NEBULA OF ANDROMEDA[1]

By JULIA M. HAWKES

INTRODUCTION

This study of the faint stars situated within the region of the Andromeda nebula was made for the purpose of determining their relative positions for two dates separated by an interval of sixteen years and for examining these positions for evidence of systematic movement which might be attributed to the relationships of these stars to the nebular forms. The study is based primarily on two photographs, taken with an interval of sixteen years, one on four nights in October, 1899, with a total exposure of nearly twelve hours, and the other on four nights in November, 1915, with a total exposure of ten hours and fifty-one minutes. These photographs were made at Northfield, Minnesota, by Professor H. C. Wilson, with the eight and one-half inch photographic refractor of the Goodsell Observatory. They were supplemented by thirteen others of shorter exposure, of this and other regions of the sky, taken with the same instrument, seven by Professor Wilson and six by the writer. These shorter exposures were used for the determination of the relative positions of a selected list of forty-eight comparison stars, and for the determination of the magnitudes of the stars measured. Eight catalogued stars situated within the region photographed were used as a basis for the determination of the coordinates of the forty-eight comparison stars. In addition to the forty-eight comparison stars, whose right ascensions and declinations for the epoch 1900 are given, the relative positions of 1222 faint stars within the limits of the nebula have been measured and are given by means of their rectangular coordinates.

[1] A dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in the University of Michigan.

THE PHOTOGRAPHIC TELESCOPE

The photographic telescope of the Goodsell Observatory was originally made in 1878 for visual observations by Alvan Clark and Sons, of Cambridgeport, Massachusetts. It has a clear aperture of eight and one-half inches and a focal length of ten and one-half feet. In 1887 the Clarks furnished a third lens of the same aperture, which, when mounted in front of the visual objective, converted it into a photographic objective with a focal length of one hundred and seven inches. This gives a photographic field two degrees in diameter on a plate four by five inches. The images show very little distortion, even at the extreme edge of the field.

A five-inch guiding telescope of the same focal length as the photographic triplet is attached to the telescope tube, and to it is fitted the micrometer of the original visual telescope. It has a reticle consisting of four spider threads, set so as to form a diamond shaped figure, approximately two minutes of arc on a side. The threads are illuminated by a small electric lamp of two-candle power. The magnifying power used in guiding was about three hundred.

THE NEGATIVES

The accompanying table (Table 1) gives a list of the negatives used in this study, with dates and durations of exposures, the positions of the center of the plates, observers, notes, etc. Seed plates were used: those of sensitometer 26 in 1896 and 1899, and of sensitometer 27 in 1915 and later years. A hydrochinon developer was used for all plates, made up as follows:

A	Water	30 oz.
	Hydrochinon	$\frac{1}{2}$ oz.
	Potassium bromide	$\frac{1}{4}$ oz.
	Sodium sulphite (desiccated)	$1\frac{1}{2}$ oz.
B	Water	30 oz.
	Caustic potash	1 oz.

Use three parts of A to one of B.

Four exposures were made on plates VII and VIII. For these exposures the telescope was set to place the guiding star successively at each corner of the diamond formed by the intersecting threads of the reticle. Plate XV, of the Pleiades, taken for magnitude studies, also has a number of exposures. All of the other plates have a single exposure. For the long exposures, Plates III and V, it was necessary to continue the exposures on successive nights. The plate holder was left in position in the telescope, carefully protected from light during the intervening time, and the work continued from night to night under as nearly the same conditions as possible.

THE MEASURING ENGINE

The plates were measured by the writer at the Goodsell Observatory with a measuring engine constructed in 1913, by William Gaertner and Company of Chicago. This engine has two screws at right angles to each other, each with a pitch of one-half of a millimeter. The heads of the screws are three and one-half inches in diameter, divided into five hundred parts. The scale of the plates made with the eight and one-half inch telescope is such that one revolution of the screw corresponds very nearly to 37″.9. By reading the graduated head to the nearest half division, as was the custom, measures were obtained to one one-thousandth of a revolution of the screw, or approximately to 0″.04. Single bisections of the star images on these plates cannot be made closer than this.

The plate carriage is mounted on ways at right angles to each other and parallel to the measuring screws. The plate carriage can be rotated through any angle and clamped in any position. Its position is determined by a graduated circle, read by opposite verniers to 0°.01.

In September, 1913, Professor H. C. Wilson compared the horizontal screw with the B scale of the Repsold measuring engine belonging to the University of Minnesota. The average error of division, taken without regard to sign, was 0.0009 mm., or 0″.068; and at only one place was an error found which was greater than 0.0030 mm. The errors of the vertical screw have not been investigated, but they have been assumed to be of the same order of magnitude as those of the horizontal screw.

COMPARISON STARS

The comparison stars used in this investigation were selected on account of having good images and a fairly uniform distribution on the plates. They range in magnitude from 7.3 to 11.5. In the beginning fifty stars were selected, but two were rejected on account of being near the edge of the field of view.

Table 2 gives the mean places of the comparison stars for 1900.0. The right ascensions and declinations of this table were calculated from the final values of the rectangular coordinates of the stars, obtained from measurements of their positions on Plates I to VIII inclusive, with reductions and adjustments by the method of least squares. The right ascensions and declinations are based upon the catalogued places of eight of these stars: namely, those numbered 18, 22, 25, 29, 38, 41, 42, and 47. In the course of the determination of the positions of the forty-eight comparison stars, the places of the eight catalogued stars were also adjusted.

The places of the catalogued stars for the epoch 1900.0, as derived from the catalogues and as used in the preliminary computations of their rectangular coordinates, are given in Table 3. In forming these places proper motions for stars 22 and 47 were applied as follows:

For star 22, $\mu = -0^{s}.0016$, $\mu' = -0''.048$,
For star 47, $\mu = +0.0072$, $\mu' = -0.067$.

These proper motions were also applied to obtain corrected positions of these stars for the epochs of the plates.

The measures of stars 25 and 29 showed them also to have appreciable proper motions, but since the catalogued positions were not sufficient to determine them, these stars were not used in the preliminary solutions.

TABLE I

LIST OF PLATES

NO.	CAT. NO.	OBS.	DATE	EXPOSURE BEGAN	EXPOSURE ENDED	CENTER OF PLATE R. A.	CENTER OF PLATE DECL.	NOTES
				h m s	h m s	h m s	° ′	
I	C129a	Wilson	1896, Aug. 6	19 17 46	20 17 56	0 37 3	+40 24	The times of exposure are Northfield Sidereal Times
II	C151a	Wilson	1899, Sept. 8	20 16 52	22 42 16	0 37 47	+40 28	
III	C152	Wilson	1899, Oct. 4	22 6 33	25 3 2	0 37 4	+40 37	
			5	19 58 50	24 59 30			
			6	22 22 52	25 3 18			
			7	20 1 7	21 21 20			
IV	L182	Hawkes	1915, Oct 28	22 25 0	23 15 0	0 37 16	+40 37	
			29	21 15 0	21 45 0			
V	L185	Wilson	1915, Nov. 1	21 24 0	1 15 0	0 37 24	+40 37	
			2	21 22 0	21 28 0			
			3	21 32 0	1 15 0			
			4	21 21 0	0 32 0			
VI	L186	Hawkes	1915, Nov. 5	22 31 0	1 16 0	0 37 16	+40 37	
VII	L274	Wilson	1916, Oct. 31	0 41 0	0 46 0	0 37 16	+40 37	
				0 47 0	0 49 0			
				0 50 0	0 52 0			
				0 53 0	0 55 0			
VIII	L287	Wilson	1916, Nov. 5	1 1 0	1 6 0	0 37 17	+40 43	
				1 7 0	1 12 0			
				1 13 0	1 18 0			
				1 19 0	1 24 0			
IX	L275	Wilson	1916, Oct. 31	1 1 0	1 6 0		+90 0	Polar region.
X	L297a	Wilson	1917, Feb. 17	7±				Andromeda Nebula and Polar region.
XI	L334	Hawkes	1917, Oct. 12	21 6 14	22 8 24	1 38 0	+40 55	
XII	L335	Hawkes	1917, Oct. 12	22 22 27	23 24 37	1 20 0	+45 0	Harvard Region B.
XIII	L346	Hawkes	1917, Nov. 14	23 18 19	23 23 20	0 38 12	+40 29	
				23 24 20	23 39 23			
				23 40 23	0 25 30			
XIV	L350	Hawkes	1917, Nov. 15	21 42 50	0 46 29	0 38 12	+40 29	
XV	L354	Wilson	1918, Feb. 18	7 18±				Pleiades. Exposures of 15^s, 30^s, 1^m, 2^m, 4^m, 8^m.

TABLE 2

MEAN PLACES FOR 1900.0 OF THE FORTY-EIGHT COMPARISON STARS

NO.	MAG.	R. A.	PREC.	DECL.	PREC.
		h m s	s	° ′ ″	″
1	11.4	0 33 22.02	+3.2381	+40 32 5.29	+19.835
2	9.2	0 33 35.10	3.2368	40 7 20.49	19.832
3	10.8	0 33 59.32	3.2398	40 17 31.04	19.827
4	10.9	0 34 0.03	3.2426	40 45 5.03	19.827
5	10.4	0 34 7.06	3.2415	40 28 58.05	19.825
6	11.0	0 34 23.95	+3.2460	+40 59 17.58	+19.821
7	11.4	0 34 29.39	3.2476	41 10 36.61	19.820
8	9.6	0 34 30.75	3.2414	40 8 4.57	19.820
9	9.8	0 34 30.90	3.2407	40 1 28.49	19.820
10	10.9	0 34 42.57	3.2469	40 53 21.68	19.817
11	10.6	0 34 44.29	+3.2483	+41 4 51.24	+19.817
12	10.6	0 34 46.23	3.2482	41 2 25.63	19.817
13	10.6	0 34 47.58	3.2464	40 43 50.76	19.816
14	10.6	0 34 57.45	3.2448	40 20 11.89	19.814
15	9.8	0 35 20.44	3.2443	39 57 36.55	19.809
16	11.2	0 35 26.29	+3.2517	+41 3 47.75	+19.808
17	10.9	0 35 28.80	3.2478	40 24 46.52	19.807
18	9.0	0 35 31.13	3.2528	41 10 56.01	19.807
19	11.2	0 35 38.87	3.2465	40 3 42.93	19.805
20	10.6	0 36 2.94	3.2532	40 40 16.58	19.799
21	11.2	0 36 16.53	+3.2525	+40 32 10.83	+19.796
22	7.3	0 36 34.82	3.2515	40 8 29.96	19.792
23	11.2	0 36 35.03	3.2550	40 40 58.17	19.792
24	10.6	0 37 0.32	3.2591	41 0 7.26	19.786
25	9.5	0 37 2.67	3.2554	40 24 24.25	19.786
26	10.6	0 37 3.50	+3.2569	+40 37 17.11	+19.785
27	11.2	0 37 5.74	3.2585	40 50 15.07	19.785
28	9.8	0 37 8.40	3.2599	40 1 21.85	19.784
29	9.3	0 37 10.42	3.2610	41 9 7.29	19.784
30	11.3	0 37 27.92	3.2558	40 8 29.05	19.780
31	9.4	0 37 31.89	+3.2542	+39 51 17.23	+19.779
32	9.8	0 37 40.54	3.2594	40 27 41.05	19.775
33	11.5	0 37 48.50	3.2613	40 43 38.70	19.775
34	11.4	0 38 4.77	3.2618	40 36 18.06	19.771
35	10.9	0 38 10.18	3.2605	40 21 23.45	19.769
36	10.2	0 38 11.47	+3.2639	+40 49 40.65	+19.769
37	10.6	0 38 13.37	3.2663	41 9 32.87	19.769
38	9.4	0 38 35.47	3.2672	41 1 24.30	19.763
39	9.3	0 38 37.30	3.2597	39 53 13.68	19.763
40	10.9	0 38 45.31	3.2635	40 21 51.75	19.761

TABLE 2

MEAN PLACES FOR 1900.0 OF THE FORTY-EIGHT COMPARISON STARS

CONTINUED

NO.	MAG.	R. A.	PREC.	DECL.	PREC.
		h m s	s	° ′ ″	″
41	9.7	0 38 48.82	+3.2623	+40 8 17.73	+19.760
42	9.1	0 39 9.06	3.2639	40 7 57.01	19.755
43	10.6	0 39 15.47	3.2665	40 30 36.40	19.753
44	9.4	0 39 18.86	3.2690	40 45 58.34	19.753
45	9.4	0 40 4.09	3.2756	41 8 55.22	19.741
46	9.8	0 40 14.40	+3.2754	+41 0 55.82	+19.739
47	8.0	0 40 33.71	3.2716	40 15 48.51	19.734
48	9.4	0 40 35.39	3.2770	40 59 23.60	19.733

TABLE 3

MEAN PLACES OF CATALOGUED STARS FOR THE EPOCH 1900.0

STAR	MAG	R. A.	DECL.	AUTHORITY
		h m s	° ′ ″	
18	8.8	0 35 31.17	+41 10 56.3	Bonn A. G. Catal. 526.
22	6.9	0 36 34.83	40 8 29.8	Mean of Rad. 185; Rad. 185G; Bonn A. G. Catal. 542; Lund A. G. Catal. 270; Second Gr. 10 yr. Catal. 216; with proper motion applied.
25	9.0	0 37 2.13	40 24 25.5	Bonn A. G. Catal. 546.
29	8.8	0 37 10.81	41 9 7.6	Bonn A. G. Catal. 550.
38	8.9	0 38 35.51	41 1 23.0	Bonn A. G. Catal. 566.
41	8.6	0 38 48.88	40 8 17.6	Mean of Rad. 195; Rad. 195G; Bonn A. G. Catal. 572; Lund A. G. Catal. 286; Second Gr. 10 yr. Catal. 228.
42	7.4	0 39 9.13	40 7 56.8	Mean of Rad. 198; Rad. 198G; Bonn A. G. Catal. 576; Lund A. G. Catal. 287; Second Gr. 10 yr. Catal. 228.
47	7.5	0 40 33.66	+40 15 48.9	Mean of Rad. 203; Rad. 203G; Bonn A. G. Catal. 593; Lund A. G. Catal. 295; Second Gr. 10 yr. Catal. 238; Küstner 297; with proper motion applied.

STANDARD COORDINATES

The *standard coordinates* of a star for a given epoch, as defined by Professor Turner, are the rectangular coordinates which the star would have on an ideal plate, truly centered and oriented, and unaffected by refraction and aberration. Let X and Y be the standard coordinates of a star whose right ascension and declination are α and δ; and let α_0 and δ_0 be the right ascension and declination of the center of the plate. The relations which these quantities sustain to each other are expressed by Turner's rigorous formulæ, as follows:

$$\begin{aligned} \tan\theta &= \tan\delta \sec(\alpha - \alpha_0), \\ X &= \tan(\alpha - \alpha_0)\sec(\theta - \delta_0)\cos\theta, \\ Y &= \tan(\theta - \delta_0). \end{aligned} \qquad (1)$$

For finding α and δ from X and Y, when α_0 and δ_0 are also given, these equations are written in the following order,

$$\begin{aligned} \tan(\theta - \delta_0) &= Y, \\ \tan(\alpha - \alpha_0) &= X\cos(\theta - \delta_0)\sec\theta, \\ \tan\delta &= \tan\theta\cos(\alpha - \alpha_0). \end{aligned} \qquad (2)$$

By expanding equations (1) and (2), Professor Jacoby expressed the values of X and Y, and of $\Delta\alpha$ and $\Delta\delta$ in series, the first terms of which are as follows:

$$X = \cos\delta_0\,[\Delta\alpha - \Delta\alpha\,\Delta\delta\tan\delta_0\sin 1'' + \Delta\alpha^3(\tfrac{1}{3} - \tfrac{1}{2}\sin^2\delta_0)\sin^2 1'' + \ldots]$$
$$Y = \Delta\delta + \tfrac{1}{4}\Delta\alpha^2\sin 2\delta_0\sin 1'' + \tfrac{1}{2}\Delta\alpha^2\Delta\delta\cos 2\delta_0\sin^2 1'' + \tfrac{1}{3}\Delta\delta^3\sin^2 1'' - \ldots \quad (3)$$

$$\Delta\alpha = X\sec\delta_0\,[1 + Y\tan\delta_0\sin 1'' + Y^2\tan^2\delta_0\sin^2 1'' + \ldots] - \tfrac{1}{3}X^3\sec^3\delta_0\sin^2 1'' + \ldots$$
$$\Delta\delta = Y - \tfrac{1}{4}(X\sec\delta_0)^2\sin 2\delta_0\sin 1'' - \tfrac{1}{2}Y(X\sec\delta_0)^2\sin^2 1'' - \tfrac{1}{3}Y^3\sin^2 1'' + \ldots \quad (4)$$

in which $\Delta\alpha = \alpha - \alpha_0$ and $\Delta\delta = \delta - \delta_0$.

The standard coordinates of the six catalogued stars which were used in the first steps in the determination of the positions of the forty-eight comparison stars are given for the epoch 1900.0 in Table 4, and for the epoch 1916.0 in Table 5. These coordinates are referred to star 26 as the origin, using as its place, for 1900.0,

$$\alpha_0 = 0^h\ 37^m\ 3^s.50, \quad \delta_0 = +40^\circ\ 37'\ 16''.7.$$

They were computed by Jacoby's formulæ, and checked by the following modification of Turner's formulæ,

$$X = (\Delta\alpha + t)\cos\theta\sec(\theta - \delta_0),$$
$$Y = \tan(\theta - \delta_0) = (\theta - \delta_0) + \tfrac{1}{3}(\theta - \delta_0)^3\sin^2 1'' + \ldots$$
$$= (\theta - \delta_0) + t \quad (5)$$

in which the value of t was taken from a small table having $(\theta - \delta_0)$ and $\Delta\alpha$ as arguments.

TABLE 4

COORDINATES FOR 1900.0 COMPUTED FROM CATALOGUED PLACES

STAR	X	Y	X'	Y'
	″	″	″	″
18	−1042.51	+2021.97	−1829.92	+2525.98
22	− 328.88	−1726.69	−1116.29	−1222.68
38	+1041.17	+1448.57	+ 253.76	+1952.58
41	+1208.40	−1736.21	+ 420.99	−1232.20
42	+1440.72	−1755.74	+ 653.31	−1251.73
47	+2405.54	−1275.95	+1618.13	− 771.94
Sums	+4724.44	−3024.05	+ 0.02	+ 0.01

$X_0 = +787''.41$
$Y_0 = -504''.01$

In Tables 4 and 5, X_0 is the mean of the X's, and Y_0 is the means of the Y's; and $X' = X - X_0$ and $Y' = Y - Y_0$, that is X_0 and Y_0 are the coordinates of the centroid of the group of stars, and X' and Y' are the coordinates of the stars referred to the centroid as an origin.

TABLE 5

COORDINATES FOR 1916.0 COMPUTED FROM CATALOGUED PLACES

STAR	X	Y	X'	Y'
	″	″	″	″
18	−1042.51	+2021.97	−1830.12	+2526.30
22	− 329.12	−1727.48	−1116.73	−1223.15
38	+1041.17	+1448.57	+ 253.56	+1952.90
41	+1208.40	−1736.21	+ 420.79	−1231.88
42	+1440.72	−1755.74	+ 653.11	−1251.41
47	+2406.99	−1277.06	+1619.38	− 772.73
Sums	+4725.65	−3025.95	+ 0.01	+ 0.03

$X_0 = +787''.61$
$Y_0 = -504''.33$

METHODS OF MEASUREMENT AND REDUCTION

In the beginning it was necessary to obtain reliable positions of the comparison stars by adjusting them to each other and to the places of the catalogued stars by the aid of measures of the plates. Plate VIII was chosen for the first measures, because it had four exposures and the clearest and sharpest images. It will be used as an example to illustrate the methods of measurement and reduction followed in this study.

The approximate position of the optical center of the plate, represented by star 26, was obtained by comparison with star 25. The measured differences of the rectangular coordinates of these

stars, when converted into differences of right ascension and declination, gave

$$\Delta\alpha = +1^{s}.37 \quad \text{and} \quad \Delta\delta = +12'\ 51''.2,$$

by means of which we have

$$\alpha = 0^{h}\ 37^{m}\ 3^{s}.50, \quad \delta = +40^{\circ}\ 37'\ 10''.7,$$

as the corresponding position of star 26. This position was used as the center of the plates in the preliminary reductions. The final position of star 26, given in Table 2, is

$$\alpha = 0^{h}\ 37^{m}\ 3^{s}.50, \quad \delta = +40^{\circ}\ 37'\ 17''.11.$$

In succession the four images of star 26 on Plate VIII were first measured, both coordinates at the same time; then, similarly, the four images of each of the other comparison stars were measured: after which, to check the constancy of the position of the plate in the measuring engine, the measures of star 26 were repeated. This check was regarded as satisfactory when the last settings agreed with the first ones to within 0.010 of a revolution of the measuring screw. After measures had been made in this manner, the plate was reversed in the engine and the measures repeated. This was to avoid direct and reversed errors.

The eight readings on the central star were subtracted from the corresponding readings on the other stars, giving eight values of the coordinates of each star, the means of which were adopted as the *measured coordinates*, referred to star 26 as an origin. The signs were determined by comparison with those of the standard coordinates computed from the catalogued positions.

Let X and Y be the standard coordinates of a star computed from its right ascension and declination, and x and y its coordinates as measured on a plate. Then the relations between these coordinates are expressed by the equations

$$\begin{aligned} X &= a + bx + cy, \\ Y &= d + ex + fy, \end{aligned} \tag{6}$$

in which a, b, c, d, e, and f are the plate constants, which take account of all corrections which are linear, such as the first order terms of refraction and aberration; also scale value, orientation of plate in telescope and measuring engine, and non-perpendicularity of the two measured coordinates, as was shown by Professor H. H. Turner, in *The Monthly Notices of the Royal Astronomical Society*, Vol. 54, pp. 11-25, November 1893.

If the centroid of a group of stars be computed and their coordinates be referred to it as an origin, then the constants a and d of equations (6) will be zero, and the separate sums of the abscissas and the ordinates will also be zero. This condition affords a useful check upon the accuracy of the calculations; by arranging the abscissas and ordinates in columns, the algebraic sum of each column should be zero.

Let X_0 and Y_0 be the coordinates of the centroid of a group of stars found by taking the means of their standard coordinates, and x_0 and y_0 be the coordinates of the centroid of the same stars as found by taking the means of their coordinates measured on a plate. Then

$$\begin{aligned} X_0 &= a + bx_0 + cy_0, \\ Y_0 &= d + ex_0 + fy_0. \end{aligned} \tag{7}$$

Further, let x' and y' be the coordinates of the stars referred to the centroid derived from the measures as an origin, and X' and Y' the corresponding coordinates derived from the computed positions. Then

$$\begin{aligned} X' &= X - X_0, & Y' &= Y - Y_0, \\ x' &= x - x_0, & y' &= y - y_0, \end{aligned}$$

and the differences of the corresponding equations (6) and (7) give

$$\begin{aligned} X' &= bx' + cy', \\ Y' &= ex' + fy'. \end{aligned} \tag{8}$$

The scale of the plates used in this investigation is such that the coefficients b and f are each very nearly 37.9, and for convenience we may put

$$\begin{aligned} m &= X' - 37.9\,x', \\ n &= Y'' - 37.9\,y', \end{aligned}$$

and equations (8) become

$$\begin{aligned} (b - 37.9)\,x' + cy' &= m, \\ ex' + (f - 37.9)\,y' &= n. \end{aligned} \tag{9}$$

The measures of each comparison star give two equations of condition of the forms (9), the solutions of which by the method of least squares give the most probable values of the constants b, c, e, and f.

The arrangement of the work, in the application of the above equations to the six catalogued stars which were used in the preliminary solutions, is shown in the accompanying tables.

Table 6 gives the coordinates of the six catalogued stars from measures of Plate VIII. In this table x_0 is the mean of the x's, and y_0 is the mean of the y's; and $x' = x - x_0$ and $y' = y - y_0$. Star 26 was taken as the origin, and, consequently, when the origin is transferred to the centroid of the measures, the coordinates of star 26 become $-x_0$, $-y_0$.

Equations of condition were formed corresponding to equations (9), using the values of x' and y' from columns four and five of Table 6 as coefficients and the corresponding values of m and n as known terms. The solution of these equations by the method of least squares gave the following values,

$$b - 37.9 = +0''.020, \qquad e = +0''.0443,$$
$$c = -0.010, \qquad f - 37.9 = +0.0157,$$

The substitution of the values of b, c, e, f in the second members of equations (8) will give the values of X' and Y' of column five of Table 7. These values of X' and Y' may, however, be more readily found by adding the corrections given in columns three and four of Table 7 to the values of $37.9\,x'$ and $37.9\,y'$, given in the sixth and seventh columns of Table 6. The residuals given in the last column of Table 7 are the differences of the corresponding values of X' and Y' in Tables 5 and 7.

When the plate constants had been found from the six catalogued stars, in the manner indicated, they were used in the same way in the reduction of the measured coordinates, x and y, of the forty-two remaining comparison stars, to give their computed coordinates, X' and Y'.

The reductions given in Table 6 and 7 are expressed in seconds of arc. They may also be made in terms of revolutions of the measuring screw. For this reduction the constants already given in arc must be divided by 37.9, and a and d, which are the residuals of star 26 in Table 7, must be similarly expressed. The constants then become

$$a = +0.0192, \qquad d = -0.0179.$$
$$b - 1 = +0.000527, \qquad f - 1 = +0.000414,$$
$$c = -0.000264. \qquad e = +0.001169.$$

By writing equations (6) in the following forms,

$$X = x + (b - 1)\,x + cy + a,$$
$$Y = y + (f - 1)\,y + ex + d, \qquad (10)$$

TABLE 6

COORDINATES OF SIX CATALOGUED STARS FROM MEASURES OF PLATE VIII

STAR	x	y	x'	y'	$37.9\,x'$	$37.9\,y'$	m	n
	r	r	r	r	"	"	"	"
18	−27.4981	+53.3640	−48.2455	+66.6716	−1828.50	+2526.85	−1.62	−0.55
22	− 8.7108	−45.5171	−29.4582	−32.2095	−1116.47	−1220.74	−0.26	−2.41
38	+27.4454	+38.1996	+ 6.6980	+51.5072	+ 253.85	+1952.12	−0.29	+0.78
41	+31.8330	−45.8224	+11.0865	−32.5148	+ 420.18	−1232.31	+0.01	+0.43
42	+37.9618	−46.3393	+17.2144	−33.0317	+ 652.43	−1251.90	+0.68	+0.49
47	+63.4524	−33.7395	+42.7050	−20.4229	+1618.52	− 774.03	+0.86	+1.30
Sums	+124.4846	−79.8457	− 0.0002	− 0.0001	+ 0.01	− 0.01	−0.02	+0.04

$x_0 = +20.7474$

$y_0 = -13.3076$

and using the constants just given, the corrections to x and y, given in columns three and four of Table 8 are readily obtained. The values of X and Y derived from the measures are given in the fifth column of this table, and those from the catalogued places of the stars in the sixth column, and the residuals in the last two columns. The results of this computation may be reduced to seconds of arc by multiplying by 37.9, since the corrections to this scale value have already been applied. The residuals in the last column are expressed in seconds of arc, and they agree with those given in Table 7.

The coordinates of all stars measured in this study were reduced in both ways, in seconds of arc and in revolutions of the measuring screw, to give a check upon the numerical work. The first steps of subtracting and averaging were checked by repetition.

When the reduction of Plate VIII was completed, the forty-eight comparison stars were next measured on Plates IV, V, VI, and VII, and reduced in the same manner as Plate VIII, by means of the same six catalogued stars. The weighted means of the coordinates from these five plates were used as standards for the year 1916.

Plates I, II, and III were then measured, and reduced by means of the same six catalogued stars, using their standard coordinates for 1900.0, as given in Table 4. A comparison of the results of these reductions with those from the other plates showed seven of the stars to have appreciable proper motions. These stars were omitted from the calculations until their proper motions could be determined. It was assumed that the proper motions of the remaining forty-one stars were negligible, or that the algebraical sum of

TABLE 7

REDUCTION OF COORDINATES TO CATALOGUED POSITIONS

STAR	$37.9\,x'$	$+.020\,x'$	$-.010\,y'$	COMPUTED X'	v
	″	″	″	″	″
18	−1828.50	−0.96	−0.67	−1830.13	−0.01
22	−1116.47	−0.59	+0.32	−1116.74	−0.01
38	+ 253.85	+0.13	−0.52	+ 253.46	−0.10
41	+ 420.18	+0.22	+0.33	+ 420.73	−0.06
42	+ 652.43	+0.34	+0.33	+ 653.10	−0.01
47	+1618.52	+0.85	+0.20	+1619.57	+0.19
26	− 786.33	−0.41	−0.13	− 786.87	+0.73

STAR	$37.9\,y'$	$+.0443\,x'$	$+.0157\,y'$	COMPUTED Y'	v
	″	″	″	″	″
18	+2526.85	−2.14	+1.05	+2525.76	−0.54
22	−1220.74	−1.30	−0.51	−1222.55	+0.60
38	+1952.12	+0.30	+0.81	+1953.23	+0.33
41	−1232.31	+0.49	−0.51	−1232.33	−0.45
42	−1251.90	+0.76	−0.52	−1251.66	−0.25
47	− 774.03	+1.89	−0.32	− 772.46	+0.27
26	+ 504.36	−0.02	+0.21	+ 503.65	−0.68

their proper motions might be regarded as zero. The places of the forty-one remaining stars were reduced to the epoch 1900.0. This was done by using the forty-one stars in a least squares solution. The two sets of plates were thus brought as close together as possible. After Plates III and V had been measured, the means of the repeated measures of the comparison stars on these plates were given some weight in establishing the adopted coordinates for the dates 1900.0 and 1916.0. These adopted rectangular coordinates are given in Tables 9 and 10, and as reduced to polar coordinates, in Table 2. The epoch 1900.0 was used.

TABLE 8
REDUCTION OF MEASURED COORDINATES IN REVOLUTIONS OF THE SCREW

STAR	x	$(b-1)\,x$	cy	MEASURED X	STANDARD X	v	v
							″
18	−27.4981	−0.0145	−0.0141	−27.5075	−27.5069	−0.0006	−0.02
22	− 8.7108	−0.0046	+0.0120	− 8.6842	− 8.6839	−0.0003	−0.01
38	+27.4454	+0.0145	−0.0101	+27.4690	+27.4715	−0.0025	−0.09
41	+31.8339	+0.0168	+0.0120	+31.8819	+31.8839	−0.0020	−0.08
42	+37.9618	+0.0200	+0.0122	+38.0132	+38.0137	−0.0005	−0.02
47	+63.4524	+0.0334	+0.0089	+63.5139	+63.5090	+0.0049	+0.19

STAR	y	$(f-1)\,y$	ex	MEASURED Y	STANDARD Y	v	v
							″
18	+53.3640	−0.0322	+0.0221	+53.3360	+53.3502	−0.0142	−0.54
22	−45.5171	−0.0102	−0.0188	−45.5640	−45.5799	+0.0159	+0.60
38	+38.1996	+0.0321	+0.0158	+38.2296	+38.2208	+0.0088	+0.33
41	−45.8224	+0.0372	−0.0190	−45.8221	−45.8103	−0.0118	−0.45
42	−46.3393	+0.0444	−0.0192	−46.3320	−46.3256	−0.0064	−0.24
47	−33.7305	+0.0742	−0.0140	−33.6882	−33.6955	+0.0073	+0.28

$a = +0.0192, \qquad d = -0.0179.$

TABLE 9
ADOPTED COORDINATES OF THE FORTY-EIGHT COMPARISON STARS FOR THE EPOCH 1900.0, FROM PLATES I, II, III

NO.	MAG.	X	Y	X''	Y''
		r	r	″	″
1	11.4	−66.6187	− 7.8731	−2524.85	− 298.39
2	9.2	−63.0700	−47.0807	−2390.35	−1784.36
3	10.8	−55.5997	−31.0150	−2107.23	−1175.47
4	10.9	−55.0296	+12.5932	−2085.62	+ 477.28
5	10.4	−53.1155	−12.9459	−2013.08	− 490.65
6	11.0	−47.6649	+35.0285	−1806.50	+1327.58
7	11.4	−45.9237	+52.9346	−1740.51	+2006.22
8	9.6	−46.2288	−46.0567	−1752.07	−1745.55
9	9.8	−46.2478	−56.5034	−1752.79	−2141.23
10	10.9	−42.1839	+25.6000	−1598.77	+ 970.24

TABLE 9

ADOPTED COORDINATES OF THE FORTY-EIGHT COMPARISON STARS FOR THE EPOCH 1900.0, FROM PLATES I. II. III — CONTINUED

NO.	MAG.	X	Y	X'''	Y'''
		r	r	"	"
11	10.6	−41.5409	+43.7826	−1574.40	+1659.36
12	10.6	−41.0541	+39.8982	−1555.95	+1512.14
13	10.6	−40.7409	+10.5311	−1544.42	+ 399.13
14	10.6	−38.0372	−26.9243	−1441.61	−1020.43
15	9.8	−31.3121	−62.7156	−1186.73	−2376.92
16	11.2	−29.0021	+42.0470	−1099.18	+1593.58
17	10.9	−28.5449	−19.7148	−1081.85	− 747.19
18	9.0	−27.5235	+53.3219	−1043.14	+2020.90
19	11.2	−25.6519	−53.0612	− 972.21	−2011.42
20	10.6	−18.1237	+19.0251	− 686.89	+ 721.25
21	11.2	−14.1356	− 8.0559	− 535.74	− 305.32
22	7.3	− 8.7021	−45.5206	− 329.81	−1725.23
23	11.2	− 8.5412	+ 5.8504	− 323.71	+ 221.73
24	10.6	− 0.9427	+36.1517	− 35.73	+1370.15
25	9.5	− 0.3177	−20.3623	− 12.04	− 771.73
26	10.6	+ 0.0129	− 0.0008	+ 0.49	− 0.03
27	11.2	+ 0.6575	+20.5486	+ 24.92	+ 778.79
28	9.8	+ 1.4847	−56.8432	+ 56.27	−2154.36
29	9.3	+ 2.1100	+50.4237	+ 79.97	+1911.06
30	11.3	+ 7.3794	−45.5646	+ 279.68	−1726.90
31	9.4	+ 8.6361	−72.7873	+ 327.31	−2758.64
32	9.8	+12.9619	−15.1892	+ 491.26	− 575.67
33	11.5	+13.4939	+10.0863	+ 511.42	+ 382.35
34	11.4	+18.4049	− 1.5237	+ 697.55	− 57.65
35	10.9	+20.0847	−25.1211	+ 761.20	− 952.09
36	10.2	+20.3644	+19.6488	+ 771.81	+ 744.49
37	10.6	+20.8329	+51.0773	+ 789.57	+1935.83
38	9.4	+27.4726	+38.2341	+1041.21	+1449.07
39	9.3	+28.4709	−69.6504	+1079.05	−2639.75
40	10.9	+30.7108	−24.3285	+1163.94	− 922.05
41	9.7	+31.8765	−45.8026	+1208.12	−1735.92
42	9.1	+37.9958	−46.3158	+1440.04	−1755.37
43	10.6	+39.7113	−10.4371	+1505.06	− 395.56
44	9.4	+40.5865	+13.8861	+1538.23	+ 526.28
45	9.4	+54.1367	+50.3000	+2051.78	+1906.36
46	9.8	+57.5602	−57.2639	+2181.53	−2170.30
47	8.0	+63.4314	−33.6443	+2404.05	−1275.12
48	9.4	+63.5219	+35.3198	+2399.90	+1338.62

TABLE 10

ADOPTED COORDINATES OF THE FORTY-EIGHT COMPARISON STARS FOR THE EPOCH 1916.0, FROM PLATES IV, V, VI, VII, VIII

NO.	X	Y	X″	Y″	ΔX	ΔY
	r	r	″	″	″	″
1	−66.6235	− 7.8687	−2525.03	− 298.22	−0.18	+0.17
2	−63.0734	−47.0871	−2390.48	−1784.60	−0.13	−0.24
3	−55.6029	−31.0200	−2107.35	−1175.66	−0.12	−0.19
4	−55.0116	+12.5963	−2084.94	+ 477.40	+0.68	+0.12
5	−53.1145	−12.9364	−2013.04	− 490.29	+0.04	+0.36
6	−47.6681	+35.0329	−1806.62	+1327.75	−0.12	+0.17
7	−45.9140	+52.9384	−1740.14	+2006.37	+0.37	+0.15
8	−46.2174	−46.0612	−1751.74	−1745.92	+0.43	−0.17
9	−46.2520	−56.5187	−1752.95	−2142.06	−0.16	−0.83
10	−42.1659	+25.6022	−1598.09	+ 970.32	+0.68	+0.08
11	−41.5319	+43.7942	−1574.06	+1659.80	+0.34	+0.44
12	−40.9823	+39.9480	−1553.13	+1514.03	+2.82	+1.89
13	−40.7554	+10.5277	−1544.63	+ 399.00	−0.21	−0.13
14	−38.0293	−26.9224	−1441.25	−1020.56	+0.36	+0.07
15	−31.2673	−62.7294	−1185.03	−2377.44	+1.70	−0.52
16	−29.0101	+42.0478	−1099.48	+1593.61	−0.30	+0.03
17	−28.5379	−19.7306	−1081.59	− 747.79	+0.26	−0.60
18	−27.5134	+53.3417	−1042.76	+2021.65	+0.38	+0.65
19	−25.6385	−53.0854	− 971.70	−2011.94	+0.51	−0.52
20	−18.1396	+19.0198	− 687.49	+ 720.85	−0.60	−0.40
21	−14.1298	− 8.0555	− 535.52	− 305.30	+0.22	+0.02
22	− 8.6794	−45.5563	− 328.95	−1726.58	+0.86	−1.35
23	− 8.5438	+ 5.8488	− 323.81	+ 221.67	−0.10	−0.06
24	− 0.9499	+36.1028	− 36.00	+1370.57	−0.27	+0.42
25	− 0.2512	−20.3819	− 9.52	− 772.47	+2.52	−0.74
26	− 0.0013	+ 0.0104	− 0.05	+ 0.39	−0.54	+0.42
27	+ 0.6705	+20.5371	+ 25.41	+ 778.35	+0.49	−0.44
28	+ 1.4852	−56.8586	+ 56.29	−2154.94	+0.02	−0.58
29	+ 2.0629	+50.4124	+ 78.18	+1910.63	−1.79	−0.43
30	+ 7.3889	−45.5818	+ 280.04	−1727.55	+0.36	−0.65
31	+ 8.6251	−72.8082	+ 326.89	−2759.43	−0.42	+0.79
32	+12.9602	−15.1757	+ 491.19	− 575.16	−0.07	+0.51
33	+13.4961	+10.0031	+ 511.50	+ 382.53	+0.08	+0.18
34	+18.4114	− 1.5211	+ 697.79	− 57.65	+0.24	0.00
35	+20.1119	−25.1206	+ 762.24	− 952.07	+1.04	+0.02
36	+20.3570	+19.6612	+ 771.53	+ 745.16	−0.28	+0.67
37	+20.8208	+51.0959	+ 789.11	+1936.53	−0.46	+0.70
38	+27.4589	+38.2554	+1040.69	+1440.88	−0.52	+0.81
39	+28.4871	−69.6786	+1079.66	−2640.82	+0.61	−1.07
40	+30.7013	−24.3327	+1163.58	− 922.21	−0.36	−0.16

TABLE 10

ADOPTED COORDINATES OF THE FORTY-EIGHT COMPARISON STARS FOR THE EPOCH 1916.0 FROM PLATES IV, V, VI VII, VIII—CONTINUED

NO.	X	Y	X''	Y''	ΔX	ΔY
	r	r	"	"	"	"
41	+31.8684	−45.8061	+1207.81	−1736.05	−0.31	−0.13
42	+37.9939	−46.3196	+1439.97	−1755.51	−0.07	−0.14
43	+39.7111	−10.4364	+1505.05	− 395.54	−0.01	+0.02
44	+40.5747	+13.8920	+1537.78	+ 526.53	−0.45	+0.25
45	+54.1208	+50.3288	+2051.08	+1907.46	−0.60	+1.10
46	+57.5660	− 57.2903	+ 2181.75	−2171.30	+0.22	−1.00
47	+63.4808	− 33.6765	+2406.26	−1276.34	+2.21	−1.22
48	+63.3032	+35.3305	+2399.19	+1339.02	−0.71	+0.40

In order to check the adopted coordinates of the catalogued stars, their positions derived from the catalogues were compared with their places found from the plates, and the annual proper motions were determined anew, as follows:

STAR	μ	μ'
	s	"
18	0.00	−0.0085
22	−0.0017	−0.050
25	−0.018	−0.032
29	−0.009	−0.0075
38	0.00	+0.032
41	0.00	−0.0042
42	0.00	0.00
47	+0.0088	−0.057

When these proper motions are applied the positions of the six original catalogued stars, for the epoch 1900.0, become,

STAR	R. A.	DECL.
	h m s	° ′ ″
18	0 35 31.10	+41 10 56.15
22	0 36 34.81	40 8 29.67
38	0 38 35.49	41 1 24.21
41	0 38 48.87	40 8 17.45
42	0 39 9.12	40 7 56.82
47	0 40 33.74	+40 15 48.00

and the corresponding values of the standard coordinates are

STAR	X	Y	ΔX	ΔY
	"	"	"	"
18	−1042.62	+2021.80	+0.14	+0.15
22	− 329.11	−1726.87	−0.16	−0.29
38	+1040.94	+1449.80	+0.25	−0.08
41	+1208.26	−1736.32	+0.45	−0.27
42	+1440.61	−1755.70	+0.64	−0.19
47	+2406.44	−1276.26	+0.18	+0.08

These residuals are the differences between these values of X and Y and those given in Table 10. They include the errors of the catalogued positions, the errors of the computed proper motions, and the errors in the measurement of Plates IV, V, VI, VII, and VIII.

MAGNITUDES

No attempt was made to determine the magnitudes of the stars on the standard scale. Their approximate magnitudes were needed, however, to see whether a magnitude correction to the coordinates would be required, since the stars measured had a range of about twelve magnitudes. It was also thought that the fainter

stars would more probably belong to the nebula than the brighter ones, and on this account it was desirable to sift them out and study their motions separately.

Plate VII and Plates IX to XV inclusive were used in determining the magnitudes. Plate VII, of the nebula, and Plate IX, of the polar region, were taken on the same night under as nearly the same conditions as possible. Enough stars with well determined magnitudes were found on Plate IX to furnish a good scale of magnitudes for the brighter stars. The magnitudes of the forty-eight comparison stars were obtained by superposing these plates.

Plate XI, of the nebula, and Plate XII, of the Harvard Region B, (R.A. $1^h\ 20^m$; Decl. $+45°$, 1900), were taken on the same night under as nearly the same conditions as possible. The stars of Region B were identified and their magnitudes, as given in the *Annals of the Harvard College Observatory*, Vol. 71, No. 4, were marked on the plate. This gave a good scale of magnitudes from 7.3 to 15.6. The first determinations of the magnitudes of the comparison stars were checked by comparison with this plate, and from it the magnitudes of a large number of faint stars were also obtained.

A simple comparator was constructed for comparing the plates. It had two objectives of very nearly the same power, and a duplex eyepiece, and was so arranged that images of strips of the two plates could be seen in the same field of view side by side. The plates were carried on a frame which permitted an up and down movement of one plate and a right and left movement of the other. The frame could also be moved back and forth under the microscope, and the microscope adjusted to right and left. By these movements any two images, one from each plate, could easily be brought into position for comparison. A mirror reflected sky light through the plates to illuminate them.

Plates XI and XII were first compared by superposition, and as many of the stars already measured for position on Plates III and V as appeared on Plate XI were measured for magnitude. The plates were then put into the comparator and the measures for magnitude repeated. The comparator was much more convenient to use, and the magnitudes obtained with it agreed very closely with those determined by superposing the plates. The means of these measures were used in most cases, a slightly greater weight being given to values obtained with the comparator where the differences were appreciable.

The magnitudes of a large number of stars were marked on Plate XI, and a careful study of the stars in small groups was made in order to determine corrections by intercomparisons. These stars were then used as standards for determining the magnitudes of the fainter stars on Plate V. Plate XV had six exposures of the Pleiades, with times of exposure ranging from fifteen seconds to eight minutes. Alcyone and the three stars near it were selected and lettered on this plate, after which it was compared with Plate V. The series of images on Plate XV overlapped and furnished a reliable series of magnitudes. The stars measured on Plate VII were remeasured on Plate V in terms of these letters, and a curve was then drawn using the letters and magnitudes as arguments. This curve was extended four magnitudes farther, and the fainter stars on Plate V were measured in letters and reduced by reading the corresponding magnitudes from the curve.

MEASUREMENT AND REDUCTION OF PLATES III AND V

More than twelve hundred stars were measured on these plates. Since they could not all be measured at a sitting, the plates were divided into sections for measurement and reduction. There were thirteen sections, so selected that they extended across the major axis of the nebula, with some of the sections overlapping, to give a check upon the work. The measures were made in the following order: A number of comparison stars were first measured; next, the stars of the section were measured; and then the same comparison stars were measured again. This constituted a half set of measures. The plate was then reversed and the measures repeated, to give the second half set. Two settings were made on each star to form a measure, and both coordinates were measured at the same time. For each section there were eight readings on each of the comparison stars used, and four readings for each of the other stars. In the first sections

measured from ten to fifteen comparison stars were used, and in the later ones twenty. The average number for all sections was sixteen and one-half.

A chart was made of each section measured, giving approximately the positions and magnitudes of the stars. The stars were numbered on the charts nearly in the order of their right ascensions, and the charts were used to identify the stars during the measurement of Plate V, and also in the determination of their magnitudes from the other plates.

TABLE II

PLATE CONSTANTS FOR SECTIONS OF PLATES III AND V

PLATE III

SECTION	a	b	c	d	e	f	r_x	r_y
	″	″	″	″	″	″	″	″
I	0.69	37.9406	+0.0224	−0.57	+0.0234	37.9179	0.12	0.17
II	0.51	37.9391	−0.0102	−0.03	0.0473	37.9184	0.08	0.11
III	0.52	37.9298	−0.0020	−0.27	0.0648	37.9144	0.11	0.15
IV	0.51	37.9391	−0.0052	−0.03	0.0473	37.9184	0.11	0.11
V	0.57	37.9270	−0.0237	−0.29	0.0678	37.9142	0.13	0.17
VI	0.49	37.9302	−0.0177	−0.13	0.0705	37.9185	0.12	0.19
VII	0.19	37.9430	+0.0050	+0.38	0.0379	37.9164	0.17	0.13
VIII	0.14	37.9429	+0.0050	+0.28	0.0379	37.9164	0.14	0.15
IX	0.58	37.9264	−0.0001	+0.06	0.0582	37.9163	0.10	0.17
X	0.58	37.9360	−0.0206	−0.07	0.0697	37.9139	0.21	0.16
XI	0.26	37.9430	+0.0100	+0.61	0.0330	37.9210	0.11	0.23
XII	0.41	37.9329	−0.0211	−0.02	+0.0742	37.9136	0.08	0.17
XIII	0.53	37.9357	+0.0300	−0.06	−0.0006	37.9300	0.18	0.22

PLATE V

SECTION	a	b	c	d	e	f	r_x	r_y
	″	″	″	″	″	″	″	″
I	−0.22	37.9352	0.0507	0.58	−0.0033	37.9188	0.20	0.20
II	−0.01	37.9379	0.0075	0.39	+0.0380	37.9208	0.09	0.08
III	−0.06	37.9314	0.0041	0.18	0.0613	37.9114	0.15	0.09
IV	−0.04	37.9338	0.0088	0.33	0.0379	37.9258	0.12	0.10
V	+0.05	37.9304	0.0121	0.38	0.0362	37.9212	0.11	0.09
VI	+0.15	37.9288	0.0127	0.39	0.0447	37.9225	0.12	0.17
VII	+0.09	37.9429	0.0075	0.39	0.0379	37.9208	0.16	0.11
VIII	+0.05	37.9397	0.0075	0.39	0.0379	37.9208	0.15	0.14
IX	−0.09	37.9290	0.0042	0.28	0.0507	37.9079	0.18	0.11
X	−0.06	37.9284	0.0112	0.61	0.0420	37.9219	0.11	0.14
XI	0.00	37.9379	0.0075	0.29	0.0379	37.9210	0.10	0.08
XII	−0.10	37.9297	0.0113	0.44	+0.0406	37.9142	0.12	0.20
XIII	+0.09	37.9319	0.0052	0.38	−0.0213	37.9341	0.14	0.18

The constants are positive, except as indicated. The r_x's and r_y's are ±.

The measures of each section were reduced in the manner already explained for the comparison stars of Plate VIII. The adopted coordinates of the comparison stars used in these reductions are given in Tables 9 and 10, and the plate constants for the several sections are given in Table 11. The plate constants include the corrections for scale value, orientation, refraction, and aberration.

Table 13 gives the measured and reduced coordinates of Messier 31, the great nebula in Andromeda; Messier 32, the small circular nebula on its south following side, first described by Le Gentil in 1749; and H. V. 18, the small elongated nebula on the north preceding side, discovered by Miss Caroline Herschel in 1783. These coordinates are for the epoch 1900.0, and are referred to star 26 as an origin.

Table 14 gives the rectangular coordinates of the stars and nebulous knots measured on Plates III and V. The stars are arranged in sections approximately in the order of their right ascensions, and assigned numbers beginning with 51. Fifty comparison stars were originally selected; of these forty-eight are retained, and numbered from 1 to 48.

In Tables 13 and 14, the *measured coordinates*, x and y, are the uncorrected values, expressed in revolutions of the screw; and the *reduced coordinates*, X and Y, are the values expressed in seconds of arc after applying corrections corresponding to the plate constants given in Table 11. The *reduced coordinates* have been checked by calculating their values from the *measured coordinates* and the plate constants by means of equations (6). The products, bx, cy, ex, and fy, were formed with a Millionaire computing machine.

A few stars belonging to other sections were measured with the stars of Section XIII and reduced with the plate constants of this section. These stars are placed in their proper sections, but they are indicated by having an asterisk placed after each measured coordinate which was measured in this manner. Some of the stars were so measured on one plate only, III or V, and others on both of these plates.

The right ascensions and declinations of the stars for the epoch 1900.0 may be found from these values of X and Y by the use of equations (2) or (4). In Table 14, V_X and V_Y, are the differences of the reduced coordinates from Plates III and V. They include the errors of measurement and reduction, and the proper motions of the stars for the sixteen year interval, from 1899 to 1915.

The differences, V_X and V_Y, for all the stars and nebulous knots, were arranged in order of magnitude, and examined for systematic errors and tested for agreement with the law of probability. The residuals given in Table 14 show a slight shift of the whole system, of about $+0''.06$ in right ascension and $-0''.04$ in declination, for the interval of sixteen years. This motion is toward the sun's antapex, and might be accounted for by the parallactic motion of the fainter stars due to the motion of the sun, the motion of the brighter stars having been eliminated in the preparation of the standard coordinates, given in Tables 9 and 10. Assuming the distance of stars of the fifteenth magnitude to be 2300 light years, as estimated by Professor Newcomb, and the motion of the sun to be twenty kilometers per second, this motion is too great to be accounted for in this manner unless it is influenced by stars of fainter magnitude.

When the residuals are arranged according to the magnitudes of the stars, a very noticeable progression is found toward the negative for the fainter stars in both right ascension and declination. This progression of residuals with magnitude is probably due to a combination of guiding error on the long exposures, to parallactic motion of the sun, and to errors of measurement. The direction in declination is consistent with the results of Boss, Dyson, Thackeray, Comstock, Stumpe, and Newcomb, all of whom in computing the position of the solar apex found a considerable increase in the declination of the apex with increasing faintness of the stars. The reverse change would be expected in the stars. Evidence of a similar but smaller change in the right ascension of the apex with increase in faintness of stars is indicated by this work.

The residuals were plotted, using magnitudes as ordinates. They gave a smooth line, slightly curved, from which a table of corrections was computed for stars fainter than the twelfth magnitude. After corrections had been applied to the stars from the twelfth to the nineteenth magnitude, the residuals were examined for comparison

of the actual and theoretical distribution of errors. The *huge error* was found to be 1″.80. Omitting stars with residuals exceeding this, the probable error was found to be 0″.34, and the actual and theoretical distribution of errors were found to be as given in Table 12.

Sections of the plates were selected and the residuals counted. These sections were compared in pairs, two at opposite ends of the spiral, two on opposite sides of the nucleus, and two along the densest parts of the spiral stream. Slight motions were detected in the sections, but they were not consistent with any motion of rotation. The same test was made, with the same result, using the residuals after the systematic motion had been eliminated by the method indicated above, and also by a change of origin of coordinates to compensate for the shift of the whole system during the interval of sixteen years.

Through the kindness of Professor Frost, I had the use of the stereocomparator at the Yerkes Observatory for making a very careful comparison of Plates III and V. The difference in the character of the plates, due to the difference in intensity of the images, made small motions difficult to detect. Slight differences in the forms of some of the nebulous knots were noted, but they were very small and too indefinite to be measured, and might easily have been due to the differences of the plates. No real motions of the nebulous knots were detected with certainty.

With the stereocomparator, one star near the edge of the plates, remote from the nebula, and entirely outside the region measured, was shown to have an appreciable proper motion.

The star, No. 543, was measured on Plate V, with an estimated magnitude of 15.5. Its appearance on this plate is in all respects similar to that of the two stars which are nearest it. It does not appear on Plate III, nor on any of the other plates, and it may be a temporary star, several of which have been reported in this nebula in recent years.

In conclusion I wish to express my thanks to those who have aided me in this study. They are hereby gratefully expressed in particular to Professor H. C. Wilson, Director of the Goodsell Observatory, under whose direction the work was begun. He suggested the problem, planned the work, and furnished a number of the plates. Throughout the work he has been a constant source of help and encouragement. My thanks are also due to the trustees of Carleton College for the use, of the instruments of the Goodsell

TABLE 12

COMPARISON OF ACTUAL AND THEORETICAL ERRORS

MAGNITUDE OF ERROR	RIGHT ASCENSION		DECLINATION	
	ACTUAL NUMBER OF ERRORS	THEORETICAL NUMBER OF ERRORS	ACTUAL NUMBER OF ERRORS	THEORETICAL NUMBER OF ERRORS
″				
0.0	193	160	146	154
0.1	331	296	346	283
0.3	206	232	225	230
0.5	132	155	137	158
0.7	60	98	64	94
0.9	34	43	41	48
1.1	22	18	25	22
1.3	12	6	14	8
1.5	9	2	8	3
1.7	0	1	0	1

Observatory; to Professor Frost for the use of the stereocomparator of the Yerkes Observatory; and to Professors W. J. Hussey, R. H. Curtiss, and W. C. Rufus, of the University of Michigan, where the work was completed and prepared for publication.

TABLE 13

MEASURED AND REDUCED COORDINATES FOR 1900.0 OF MESSIER 31, MESSIER 32, AND H. V. 18

MESSIER 31, THE ANDROMEDA NEBULA

PLATE	MEASURED COORDINATES		REDUCED COORDINATES	
	x	y	X	Y
	r	r	"	"
I	+ 4.0288	+ 9.4730	+ 152.37	+ 359.71
II	4.0008	9.4250	151.52	358.15
IV	4.0190	9.4528	151.38	359.73
VI	3.9642	9.4748	150.57	359.57
VII	3.9761	9.4696	150.75	359.39
VIII	+ 3.9920	+ 9.4496	+ 151.47	+ 358.51
Mean			+ 151.34	+ 359.18

MESSIER 32

PLATE	MEASURED COORDINATES		REDUCED COORDINATES	
	x	y	X	Y
	r	r	"	"
I	+ 3.3415	−28.8770	+ 127.34	−1094.08
II	3.3292	28.8735	127.55	1093.96
IV	3.2628	28.8742	126.37	1093.74
VI	3.3420	28.8872	125.86	1094.87
VII	3.3339	28.8758	127.20	1094.52
VIII	+ 3.3427	−28.8774	+ 127.17	−1094.76
Mean			+ 126.91	−1094.32

TABLE 13

MEASURED AND REDUCED COORDINATES FOR 1900.0 — CONTINUED

H. V. 18

PLATE	MEASURED COORDINATES		REDUCED COORDINATES	
	x	y	X	Y
	r	r	″	″
I	−38.0672	+49.1078	−1445.82	+1859.29
II	38.0948	49.1008	1446.70	1859.04
IV	37.9820	49.1313	1445.42	1858.52
VI	−38.1580	+49.0880	−1446.94	+1859.83
Mean			−1446.22	+1859.17

TABLE 14

SECTION Ia. MEASURED COORDINATES

NO.	MAG.	PLATE III		PLATE V	
		x	y	x	y
		r	r	r	r
51	13.3	+33.2074	+29.3750	+33.2052	+29.3755
52	10.8	33.3762	21.8560	33.3696	21.8670
53	11.9	33.7044	33.4395	33.7163	33.4458
54	16.8	34.2736	32.9632	34.2826	32.9538
55	15.7	34.3460	29.6760	34.3488	29.6742
56	16.4	+34.4084	+23.0530	+34.4176	+23.0370
57	15.9	34.6162	24.4415	34.6250	24.4122
58	17.3	34.7032	23.4148	34.6838	23.4038
59	16.2	35.0676	32.8492	35.0938	32.8172
60	16.8	35.4110	24.5127	35.4333	24.5312
61	12.7	+35.6170	+29.8672	+35.6215	+29.8715
62	16.3	35.6499	30.4272	35.6410	30.4102
63	16.2	35.7052	23.9738	35.6923	23.9582
64	15.7	35.8732	31.7160	35.8670	31.7122
65	17.9	35.9019	31.2195	35.8908	31.2005
66	16.2	+36.4889	+23.2932	+36.5015	+23.2862
67	16.2	36.6394	23.7262	36.6326	23.7332
68	16.4	36.6556	31.7710	36.6438	31.7602
69	17.3	36.7374	25.2552	36.7320	25.2410
70	11.3	36.8409	32.5075	36.8376	32.5082
71	17.3	+37.3304	+26.0352	+37.3436	+26.0712
72	15.7	37.5189	24.0165	37.5308	24.0088
73	16.8	37.7659	23.9568	37.7918	23.9370
74	15.9	37.8714	26.6035	37.8878	26.6098
75	17.9	37.9359	32.9710	37.9115	32.9480
76	17.5	+38.0076	+24.6932	+37.9858	+24.6910
77	15.7	38.0526	29.8040	38.0620	29.7005
78	13.9	38.1309	25.6630	38.1540	25.6742
79	12.8	38.3916	27.8368	38.3996	27.8380
80	17.5	38.7854	22.5258	38.7978	22.5000
81	15.2	+38.7896	+26.0348	+38.8043	+26.0595
82	16.7	39.2924	30.0515	39.2988	30.0315
83	13.2	39.3019	26.9080	39.3213	26.9060
84	15.2	39.3164	26.2222	39.3123	26.2232
85	15.7	39.3406	33.8512	39.3313	33.8442
86	16.2	+40.6334	+31.2558	+40.6326	+31.2568
87	16.8	40.9672	33.2535	40.9626	33.2282
88	16.8	40.9879	24.7798	40.9823	24.7752
89	17.9	41.0142	24.0300	41.0776	24.0488
90	14.2	41.2676	32.5835	41.2820	32.5725

TABLE 14

SECTION Ia. REDUCED COORDINATES

NO.	PLATE III		PLATE V		V_X V−III	V_Y V−III
	X	Y	X	Y		
	″	″	″	″	″	″
51	+1261.26	+1114.05	+1260.92	+1114.35	−0.34	+0.30
52	1267.49	828.94	1266.77	829.64	−0.72	+0.70
53	1280.20	1268.17	1280.51	1268.69	+0.31	+0.52
54	1301.79	1250.13	1301.97	1250.04	+0.18	−0.09
55	1304.50	1125.49	1304.31	1125.68	−0.19	+0.19
56	+1306.68	+ 874.36	+1306.59	+ 874.00	−0.09	−0.36
57	1314.60	927.01	1314.52	926.15	−0.08	−0.86
58	1317.87	888.08	1316.70	887.91	−1.17	−0.17
59	1331.91	1245.82	1332.73	1244.85	+0.82	−0.97
60	1344.79	929.73	1345.19	930.66	+0.40	+0.93
61	+1352.72	+1132.76	+1352.60	+1133.15	−0.12	+0.39
62	1353.95	1154.00	1353.37	1153.58	−0.58	−0.42
63	1355.90	909.30	1354.99	908.93	−0.91	−0.37
64	1362.45	1202.87	1362.01	1202.95	−0.44	+0.08
65	1363.53	1184.05	1362.89	1183.89	−0.64	−0.16
66	+1385.62	+ 883.51	+1385.65	+ 883.44	+0.03	−0.07
67	1391.34	899.94	1390.65	900.39	−0.69	+0.45
68	1392.14	1204.98	1391.48	1204.77	−0.66	−0.21
69	1395.09	957.91	1394.50	957.57	−0.59	−0.34
70	1399.18	1232.91	1398.87	1233.13	−0.31	+0.22
71	+1417.61	+ 987.50	+1417.74	+ 989.05	+0.13	+1.55
72	1424.72	910.96	1424.74	910.84	+0.02	−0.12
73	1434.09	908.71	1434.63	908.12	+0.54	−0.59
74	1438.15	1009.07	1438.41	1009.47	+0.26	+0.40
75	1440.74	1250.51	1439.63	1249.80	−1.11	−0.71
76	+1443.27	+ 936.63	+1442.03	+ 936.71	−1.24	+0.08
77	1445.10	1130.43	1445.18	1130.07	+0.08	−0.36
78	1447.97	973.41	1448.46	973.99	+0.49	+0.58
79	1457.91	1055.84	1457.89	1056.04	−0.02	+0.20
80	1472.74	854.47	1472.72	853.63	−0.02	−0.84
81	+1472.97	+ 987.52	+1473.15	+ 988.60	+0.18	+1.08
82	1492.14	1139.84	1492.11	1139.21	−0.03	−0.63
83	1492.43	1020.64	1492.81	1020.69	+0.38	+0.05
84	1492.97	994.64	1492.43	994.80	−0.54	+0.16
85	1494.05	1283.92	1493.54	1283.78	−0.51	−0.14
86	+1543.05	+1185.54	+1542.77	+1185.67	−0.28	+0.13
87	1555.76	1261.29	1555.39	1260.42	−0.37	−0.87
88	1556.35	939.99	1555.71	939.89	−0.64	−0.10
89	1557.33	912.32	1559.29	912.35	+1.96	+0.03
90	1567.14	1235.89	1567.47	1235.55	+0.33	−0.34

TABLE 14

SECTION Ia. MEASURED COORDINATES — CONTINUED

NO.	MAG	PLATE III		PLATE V	
		x	y	x	y
		τ	τ	τ	τ
91	15.4	+41.3974	+29.8540	+41.3958	+29.8485
92	15.2	41.7132	32.7192	41.7198	32.7202
93	11.3	41.8672	23.9398	41.8990	23.9460
94	15.5	42.4452	33.4368	42.4386	33.4340
95	15.2	43.1624	25.9785	43.1753	25.9578
96	16.8	+43.5626	+25.2810	+43.5590	+25.2705
97	17.9	43.7366	24.8878	43.7310	24.8740
98	16.8	45.9596	31.0815	45.9538	31.0822
99	15.2	46.0372	22.6958	46.0503	22.6870
100	14.4	46.0639	28.7375	46.0860	28.7370
101	14.7	+46.2169	+29.1235	+46.2388	+29.1345
102	15.7	46.6212	28.3822	46.6210	28.3752
103	13.3	46.6522	32.9920	46.6676	33.0035
104	13.7	46.8486	25.4597	46.8620	25.4752
105	14.2	46.9569	27.6408	46.9695	27.6542
106	15.2	+47.0122	+24.0285	+47.0068	+24.0265

SECTION Ib. MEASURED COORDINATES

107		+13.7136	+ 6.2032		
108	11.9	14.6936	− 4.3040	+14.7120	− 4.3090
109	17.6	14.7449	+ 3.8158	14.7506	+ 3.8272
110	17.9	14.9046	+ 6.3450		
111	16.8	15.1326	+ 3.4845	+15.1745	+ 3.4510
112	14.2	+15.5534	− 0.3412	+15.5798	− 0.3505
113	16.8	16.1909	+ 3.0708	16.2013	+ 3.0510
114	16.2	16.2706	+ 7.3078	16.2993	+ 7.2660
115	15.5	16.4744	+ 6.5712	16.5020	+ 6.5582
116	14.0	17.0014	+ 6.6755	17.0448	+ 6.6705
117	15.2	+17.1134	+ 7.1190	+17.1426	+ 7.1022
118	12.6	17.1262	+ 2.5542	17.1533	+ 2.5405
119	16.8	17.1289	+ 4.1852	17.1853	+ 4.1780
120	16.2	17.3559	+ 0.8375	17.3921	+ 0.7870
121	15.5	17.4556	+ 3.3500	17.4726	+ 3.2952
122	17.6	+17.5724	+ 7.1042	+17.5948	+ 7.0860
123	15.5	18.4922	+ 3.2340	18.5160	+ 3.2110
34	10.5	18.3762	− 1.5190	+18.4065	− 1.5445
124	15.2	18.8674	+ 5.3852	18.8848	+ 5.3715
125	16.0	19.7189	+ 7.2802	19.7326	+ 7.2645

TABLE 14

SECTION Ia. REDUCED COORDINATES — CONTINUED

NO.	PLATE III		PLATE V		V_X	V_Y
	X	Y	X	Y	V − III	V − III
	″	″	″	″	″	″
91	+1572.00	+1132.40	+1571.65	+1132.26	−0.35	−0.14
92	1584.05	1241.05	1584.09	1241.15	+0.04	+0.10
93	1589.69	908.16	1590.44	908.45	+0.75	+0.29
94	1611.84	1268.28	1611.39	1268.22	−0.45	−0.06
95	1638.88	985.49	1638.96	984.73	+0.08	−0.76
96	+1654.05	+ 959.05	+1653.48	+ 958.66	−0.57	−0.39
97	1660.64	944.15	1659.99	943.63	−0.65	−0.52
98	1745.12	1170.05	1744.62	1179.03	−0.50	−0.02
99	1747.88	861.08	1747.86	860.69	−0.02	−0.39
100	1749.03	1090.17	1749.52	1090.10	+0.49	−0.07
101	+1754.84	+1104.81	+1755.34	+1105.17	+0.50	+0.36
102	1770.16	1076.71	1769.80	1076.38	−0.36	−0.33
103	1771.44	1251.51	1771.80	1251.88	+0.36	+0.37
104	1778.72	965.90	1778.79	966.41	+0.07	+0.51
105	1782.88	1048.61	1782.98	1049.04	+0.10	+0.43
106	+1784.90	+ 911.64	+1784.21	+ 911.48	−0.69	−0.16

SECTION Ib. REDUCED COORDINATES

107	+ 521.13	+ 234.96				
108	558.08	− 163.42	+ 557.66	− 162.86	−0.42	+0.56
109	560.21	+ 144.46	559.54	+ 145.65	−0.67	+1.19
110	566.32	+ 240.37				
111	574.91	+ 131.91	575.60	+ 131.39	+0.69	−0.52
112	+ 590.79	− 13.14	+ 590.78	− 12.76	−0.01	+0.38
113	615.05	+ 116.25	614.53	+ 116.22	−0.52	−0.03
114	618.17	+ 276.91	618.47	+ 276.04	+0.30	−0.87
115	625.89	+ 248.98	626.12	+ 249.20	+0.23	+0.22
116	645.88	+ 252.95	646.72	+ 253.46	+0.84	+0.51
117	+ 650.14	+ 269.77	+ 650.45	+ 269.83	+0.31	+0.06
118	650.53	+ 96.68	650.62	+ 96.86	+0.09	+0.18
119	650.66	+ 158.52	651.92	+ 158.95	+1.26	+0.43
120	659.20	+ 31.59	659.59	+ 30.36	+0.39	−1.23
121	663.04	+ 126.86	662.77	+ 125.47	−0.27	−1.39
122	+ 667.56	+ 269.22	+ 667.60	+ 269.21	+0.04	−0.01
34	697.86	− 57.74	697.96	− 58.05	+0.10	−0.31
123	702.37	+ 122.49	702.35	+ 122.28	−0.02	−0.21
124	716.65	+ 204.10	716.45	+ 204.20	−0.20	+0.13
125	749.00	+ 275.94	748.71	+ 275.98	−0.29	+0.04

TABLE 14

SECTION Ib. MEASURED COORDINATES — CONTINUED

NO.	MAG.	PLATE III		PLATE V	
		x	y	x	y
		r	r	r	r
126	14.7	+20.2954	+ 1.9345	20.3215	+ 1.9022
127	14.0	20.3492	+ 2.2468	+20.3828	+ 2.2400
128	15.5	20.3854	+ 0.0370	20.4098	+ 0.0182
129	14.7	20.7719	+ 6.4610	20.7970	+ 6.4412

SECTION II. MEASURED COORDINATES

130	16.4	+30.5252	+63.7346	+30.5117	+63.7340
131	14.2	30.8160	59.0974	30.8110	59.1032
132	17.1	31.0308	62.9881	31.0052	62.9920
133	15.5	31.3852	65.4194	31.3754	65.4135
134	17.9	31.4045	62.5764		
135	15.5	+31.5675	+58.5966	+31.5460	+58.6112
136	15.7	31.9582	60.3821	31.9484	60.3855
137	16.8	32.1925	63.0148	32.1907	63.0330
138	16.2	32.4798	50.0158	32.4892	50.0208
139	11.8	32.6390	69.4332	32.6437	69.4368
140	16.8	+32.8355	+52.2986	+32.8217	+52.3105
141	15.7	32.8525	56.3768	32.8367	56.3510
142	16.2	32.9078	66.9701	32.9092	66.9660
143	15.2	32.9638	69.5386	32.9777	69.5302
144	16.6	32.9728	62.0578	32.9777	62.0192
145	17.0	+33.2115	+49.5366	+33.2174	+49.5162
146	16.8	33.2598	61.4411	33.2344	61.4325
147	16.8	33.3078	66.8356		
148	15.4	33.3505	65.4321	33.3604	65.4405
149	15.0	33.5162	63.2776	33.5135	63.2682
150	13.5	+34.7480	+69.0066	+34.7507	+69.0115
151	14.7	34.9492	53.7271	34.9642	53.7168
152	15.7	35.0275	56.2656	35.0170	56.2532
153	14.3	35.1458	52.8231	35.1467	52.8228
154	15.7	35.2118	66.7321	35.1830	66.7245
155	13.3	+35.2585	+52.0231	+35.2620	+52.0302
156	13.7	35.3935	69.5353	35.3967	69.5370
157	15.7	35.5195	67.5974	35.5304	67.6022
158	14.9	35.6445	60.7984	35.6435	60.7975
159	16.6	36.4078	71.4331	36.4040	71.4308

TABLE 14

SECTION Ib. REDUCED COORDINATES — CONTINUED

NO.	PLATE III		PLATE V		V_X	V_Y
	X	Y	X	Y	V − III	V − III
	″	″	″	″	″	″
126	+ 770.75	+ 73.20	+ 770.78	+ 72.64	+0.03	−0.62
127	772.80	+ 85.10	773.12	+ 85.45	+0.32	+0.35
128	774.13	+ 1.31	774.03	+ 1.20	−0.10	−0.11
129	788.03	+ 244.90	789.04	+ 244.75	+0.11	−0.15

SECTION II. REDUCED COORDINATES

130	+1157.96	+2418.13	+1158.02	+2418.39	+0.06	+0.26
131	1169.04	2242.31	1169.34	2242.80	+0.30	+0.49
132	1177.15	2389.85	1176.73	2390.28	−0.42	+0.43
133	1190.57	2482.05	1190.80	2482.11	+0.23	+0.06
134	1191.33	2374.25				
135	+1197.55	+2223.35	+1197.22	+2224.17	−0.33	+0.82
136	1212.30	2291.07	1212.50	2291.47	+0.14	+0.40
137	1221.22	2390.91	1221.71	2391.87	+0.49	+0.96
138	1232.25	1898.03	1232.94	1898.45	+0.69	+0.42
139	1238.10	2634.31	1238.94	2634.73	+0.84	+0.42
140	+1245.73	+1984.60	+1245.57	+1985.29	−0.16	+0.69
141	1246.33	2130.24	1246.17	2138.51	−0.16	−0.73
142	1248.32	2541.27	1249.00	2541.04	+0.68	−0.23
143	1250.42	2638.32	1251.62	2638.51	+1.20	+0.19
144	1250.84	2354.66	1251.56	2353.46	+0.72	−1.20
145	+1260.02	+1879.89	+1260.56	+1879.35	+0.54	−0.54
146	1261.73	2331.29	1261.29	2331.22	−0.44	−0.07
147	1263.50	2535.84				
148	1265.13	2482.03	1266.10	2483.21	+0.97	+0.58
149	1271.44	2400.94	1271.90	2400.84	+0.46	−0.10
150	+1318.11	+2618.23	+1318.88	+2618.68	+0.77	+0.45
151	1325.90	2038.87	1326.86	2038.70	+0.96	−0.17
152	1328.85	2135.13	1328.88	2134.89	+0.03	−0.24
153	1333.37	2004.60	1333.78	2004.81	+0.41	+0.21
154	1335.73	2532.01	1335.26	2531.97	−0.47	−0.04
155	+1337.66	+1974.27	+1338.15	+1974.76	+0.49	+0.49
156	1339.18	2638.31	1339.97	2638.63	+0.79	+0.32
157	1347.40	2564.84	1348.45	2565.27	+1.05	+0.43
158	1352.21	2307.03	1352.69	2307.23	+0.48	+0.20
159	1381.96	2710.32	1381.62	2710.49	+0.56	+0.17

TABLE 14

SECTION II. MEASURED COORDINATES — CONTINUED

NO.	MAG.	PLATE III		PLATE V	
		x	y	x	y
		r	r	r	r
160	15.7	+36.5118	+54.2116	+36.5097	+54.2255
161	15.2	36.6648	61.9864	36.6672	61.9902
162	16.2	36.8792	65.6124	36.8677	65.5972
163	13.5	36.9018	66.6096	36.8902	66.6190
164	15.5	36.9258	69.8904	36.9020	69.8792
165	15.9	+36.9652	+57.1258	+36.9552	+57.1195
166	16.2	37.0460	53.0164	37.0454	52.9915
167	16.8	37.0515	49.7006	37.0460	49.7135
168	16.8	37.2048	66.9691	37.2110	66.9898
169	16.5	37.3090	65.0441	37.2947	65.0420
170	15.2	+37.5472	+62.9636	+37.5530	+63.0108
171	14.2	37.6320	60.7341	37.6192	60.7170
172	16.0	37.7285	50.4626	37.7197	50.4642
173	17.3	38.0955	69.2276	38.0892	69.2382
174	16.8	38.5280	69.0961	38.5262	69.0920
175	15.7	+38.6448	+53.5274	+38.6289	+53.5140
176	15.7	38.9280	58.2541	38.8642	58.2360
177	14.2	39.1252	55.0723	38.1230	55.0795
178	16.5	39.2492	60.2458	39.2417	60.2532
179	14.2	39.4175	71.7723	39.4175	71.7710
180	17.0	+40.1025	+66.2711	+40.0837	+66.2930
181	16.8	40.3196	51.3708	40.2762	51.3570
182	16.8	40.4745	58.5744	40.4697	58.5750
183	11.9	40.6075	61.9881	40.6044	61.9902
184	15.5	41.0858	55.5821	41.0854	55.5935
185	15.4	+41.1810	+72.0896	+41.1632	+72.0885
186	13.7	41.3478	57.4096	41.3564	57.4108
187	15.2	42.0055	63.0746	42.0029	63.0640
188	12.8	42.1275	61.4218	42.1300	61.4252
189	14.0	42.1492	53.0231	42.1402	53.0363
190	15.9	+42.6752	+64.1466	+42.6700	+64.1525
191	17.1	43.0442	69.9536	43.0324	69.9500
192	16.8	43.2260	70.0496	43.1957	70.0472
193	14.7	43.3172	51.3654	43.3247	51.3625
194	15.7	43.3845	62.9786	43.3617	62.9628
195	11.9	+43.8458	+62.4461	+43.8402	+62.4462
196	13.3	43.9798	59.8894	43.9620	59.8968
197	17.3	44.2875	64.4046	44.2887	64.4065
198	16.8	44.3265	62.2156	44.3250	62.1858
199	15.2	44.7132	70.8548	44.6872	70.8280

TABLE 14

SECTION II. REDUCED COORDINATES Continued

NO.	PLATE III		PLATE V		V_X	V_Y
	X	Y	X	Y	V−III	V−III
	″	″	″	″	″	″
160	+1385.18	+2057.31	+1385.50	+2058.05	+0.32	+0.74
161	1390.91	2352.13	1391.53	2352.50	+0.62	+0.37
162	1399.00	2489.63	1399.17	2489.29	+0.17	−0.34
163	1399.85	2527.44	1400.03	2528.04	+0.18	+0.60
164	1400.73	2651.85	1400.50	2651.67	−0.23	−0.18
165	+1402.35	+2167.84	+1402.42	+2167.81	+0.07	−0.03
166	1405.40	2012.02	1405.81	2011.28	+0.35	−0.74
167	1405.70	1886.29	1405.81	1886.97	+0.11	+0.68
168	1411.34	2541.09	1412.20	2542.11	+0.86	+1.02
169	1415.32	2468.10	1415.36	2468.25	+0.04	+0.15
170	+1424.37	+2389.22	+1425.14	+2391.24	+0.77	+2.02
171	1427.61	2304.69	1427.64	2304.26	+0.03	−0.43
172	1431.38	1915.22	1431.37	1915.47	−0.01	+0.25
173	1445.11	2626.77	1445.53	2627.41	+0.42	+0.64
174	1461 52	2621 81	1462.11	2621.88	+0.59	+0.07
175	+1466.11	−2031.47	+1465.89	+2031.15	−0.22	−0.32
176	1476.81	2210.71	1474 85	2210.22	−1.96	−0.49
177	1484 32	2090.07	1484.65	2090.54	+0.33	+0.47
178	1488.97	2286.25	1489.19	2286.73	+0.22	+0.48
179	1495.24	2723.33	1495.95	2723.50	+0.71	+0.17
180	+1521.20	+2514.76	−1521.18	+2515.80	−0.11	+1.04
181	1529.68	1940.78	1528.37	1949.42	−1.31	−0.36
182	1535.48	2222.93	1535.76	2223.14	+0.28	+0.21
183	1540.40	2352.38	1540.90	2352.65	+0.41	+0.27
184	1558.70	2109.50	1559.10	2110.10	+0.40	+0.60
185	+1562.14	+2735.44	+1562.18	+2735.61	+0.04	+0.17
186	1568.62	2178.81	1569.40	2179.02	+0.78	+0.21
187	1593.52	2303.64	1593.96	2393.42	+0.44	−0.22
188	1598.16	2330.98	1598.77	2331.28	+0.61	+0.30
189	1599.07	2012.51	1599.10	2013.17	+0.03	+0.66
190	+1618.91	+2434.32	+1619.28	+2434.73	+0.37	+0.41
191	1632.85	2654.53	1633.07	2654.59	+0.22	+0.06
192	1639.75	2658.18	1639.27	2658.28	−0.48	+0.10
193	1643.40	1949.71	1644.02	1949.74	+0.62	+0.03
194	1645.84	2390.07	1645.51	2389.64	−0.33	−0.43
195	+1663.34	+2369.90	+1663.66	2370.07	+0.32	+0.17
196	1668.45	2272.96	1668.27	2273.40	−0.18	+0.44
197	1680.08	2444.18	1680.69	2444.42	+0.61	+0.24
198	1681.58	2361.18	1682.05	2360.21	+0.47	−0.97
199	1696.17	2688.79	1695.86	2687.94	−0.31	−0.85

TABLE 14

SECTION II. MEASURED COORDINATES — CONTINUED

NO.	MAG.	PLATE III		PLATE V	
		x	y	x	y
		r	r	r	r
200	12.3	+44.7398	+54.7071	+44.7264	+54.7168
201	16.8	45.0268	69.4276	44.9887	69.4228
202	14.7	45.3885	63.3658	45.3778	63.3688
203	14.9	45.4397	53.0541	45.4282	53.0535
204	17.3	45.5030	58.4364	45.4516	58.4428
205	15.7	+45.5218	+50.9541	+45.5204	+50.9535
206	15.5	45.8558	56.2754	45.8491	56.3008
207	11.2	45.8892	69.4806	45.8912	69.4802
208	16.0	46.2395	62.4493	46.2076	62.4460
209	14.2	46.2512	61.0336	46.2368	61.0355
210	14.3	+46.4220	+67.8138	+46.4104	+67.8258
211	16.8	46.6230	57.4584	46.6284	57.4385
212	15.2	46.0312	70.4561	46.0004	70.4378
213	14.0	47.2205	55.4082	47.2164	55.4205
214	16.8	47.8168	63.9316	47.8017	63.9310
215	17.9			+47.8688	+56.3698
216	15.7	+48.1510	+69.5074	48.1324	69.4910
217	13.1	48.3102	53.0143	48.2961	53.0312
218	16.8	48.3382	67.4986	48.3256	67.5000
219	15.2	48.3868	69.4864	48.3707	69.4725
220	16.0	+48.4475	+58.7041	+48.4024	+58.7008
221	15.7	48.7802	54.3398	48.7764	54.3470
222	16.8	48.8003	67.9424	48.7541	67.9408
223	16.8	49.1372	63.3334	49.1042	63.3230
224	16.2	49.3408	55.8961	49.3371	55.8758
225	14.7	+49.6695	+50.0304	+49.6431	+50.0262
226	14.7	49.8248	62.3306	49.8121	62.3270
227	13.4	49.9462	65.1796	49.9362	65.1735
228	15.7	50.1578	56.7546	50.1424	56.7448
229	15.2	50.3138	67.6816	50.2847	67.6795
230	15.5	+50.4182	+69.0163	+50.4134	+69.0162
231	16.2	50.7319	67.9304	50.7124	67.9145
232	16.8	51.0215	65.9141		
233	17.9	51.1488	61.8851	51.0760	61.8918
234	14.5	51.5616	61.1291	51.5467	61.1250
235	16.6	+51.6785	+63.4508	+51.6512	+63.4410
236	14.4	51.6795	62.6381	51.6635	62.6472
237	16.6	52.1905	63.1006	52.1837	63.1098
238	14.7	52.2322	60.5828	52.2147	60.5848
239	14.4	52.7214	71.5551	52.7057	71.5610

TABLE 14

SECTION II. REDUCED COORDINATES — CONTINUED

NO.	PLATE III		PLATE V		V_X	V_Y
	X	Y	X	Y	V−III	V−III
	″	″	″	″	″	″
200	+1097.34	+2076.49	+1097.23	+2076.99	−0.11	+0.50
201	1708.08	2634.68	1707.29	2634.67	−0.79	−0.01
202	1721.86	2404.85	1722.00	2405.11	+0.14	+0.26
203	1723.91	2013.85	1723.84	2013.95	−0.07	+0.10
204	1726.20	2217.94	1724.77	2218.31	−1.49	+0.37
205	+1727.05	+1934.22	+1727.32	+1934.32	+0.27	+0.10
206	1739.66	2136.01	1739.83	2137.10	+0.17	+1.09
207	1740.80	2636.73	1741.53	2636.88	+0.73	+0.15
208	1754.16	2370.13	1753.48	2370.15	−0.68	+0.02
209	1754.62	2316.45	1754.57	2316.66	−0.05	+0.21
210	+1761.03	+2573.56	+1761.21	+2574.16	+0.18	+0.60
211	1768.76	2180.91	1769.40	2180.28	+0.64	−0.63
212	1780.32	2673.77	1779.82	2673.23	−0.50	−0.54
213	1791.45	2103.19	1791.70	2104.00	+0.25	+0.81
214	1813.98	2426.42	1813.97	2426.52	−0.01	+0.10
215			+1816.45	+2139.80		
216	+1826.61	+2637.86	1826.55	2637.37	−0.06	−0.49
217	1832.81	2012.47	1832.04	2013.21	−0.17	+0.74
218	1833.73	2561.70	1833.87	2561.88	+0.14	+0.18
219	1835.55	2637.07	1835.59	2636.68	+0.04	−0.39
220	+1837.97	+2228.23	+1836.72	+2228.21	−1.25	−0.02
221	1850.63	2062.76	1850.87	2063.13	+0.24	+0.37
222	1851.26	2578.55	1850.13	2578.61	−1.13	+0.06
223	1864.09	2403.80	1863.38	2403.51	−0.71	−0.29
224	1871.89	2121.79	1872.16	2121.12	+0.27	−0.67
225	+1884.42	+1890.39	+1883.72	+1899.31	−0.70	−0.08
226	1890.18	2365.80	1890.22	2365.77	+0.04	−0.03
227	1894.76	2473.84	1894.95	2473.72	+0.19	−0.12
228	1902.87	2154.39	1902.71	2154.10	−0.16	−0.29
229	1908.68	2568.73	1908.19	2568.76	−0.49	+0.03
230	+1912.63	+2610.34	+1913.09	+2610.46	+0.46	+0.12
231	1924.54	2578.18	1924.42	2577.69	−0.12	−0.49
232	1935.55	2501.74				
233	1940.42	2348.07	1938.17	2349.32	−2.25	+0.35
234	1956.09	2320.33	1956.02	2320.26	−0.07	−0.07
235	+1960.50	+2408.37	+1960.00	+2408.09	−0.50	−0.28
236	1960.54	2377.55	1960.46	2377.99	−0.08	+0.44
237	1979.93	2395.11	1980.20	2395.55	+0.27	+0.44
238	1981.53	2299.64	1981 36	2299.80	−0.17	+0.16
239	1999.98	2715.72	2000.07	2716.04	+0.09	+0.32

TABLE 14

SECTION II. MEASURED COORDINATES — CONTINUED

NO.	MAG.	PLATE III		PLATE V	
		x	y	x	y
		r	r	r	r
240	16.8	+53.0408	+57.9264	+53.0204	+57.8996
241	14.7	53.3198	70.7886	53.2872	70.7775
242	16.8	53.5980	58.6106	53.5884	58.5925
243	17.9	53.6065	57.7568	53.5917	57.7780
244	16.8	53.9108	56.3126	53.9047	56.3232
245	17.9	+53.9708	+56.7526	+53.9477	+56.7262
45	9.7	54.0640	50.2191	54.0472	50.2400
246	17.9			54.2170	58.2678
247	17.9	54.4945	58.1621	54.4652	58.1878
248	17.7	54.9448	58.1866	54.9342	58.1805

SECTION III. MEASURED COORDINATES

249	15.6	+30.3942	+43.3944	+30.3998	+43.3951
250	18.4	30.4002	44.1792	30.4258	44.1958
251	13.3	31.3268	39.0839	31.3258	39.0834
252	18.2	31.8432	43.8104	31.8648	43.7561
253	19.0	32.0162	39.0562	32.0418	39.0461
254	15.7	+32.2277	+42.7184	+32.2158	+42.7254
255	16.8	32.5098	45.4699	32.5144	45.4778
256	16.5	32.8300	46.7304	32.8351	46.7273
257	17.9	32.8672	45.4784	32.8811	45.4531
258	14.7	32.8982	40.4652	32.9141	40.4598
259	17.9	+33.1325	+36.4064	+	+
260	17.9	33.7540	39.2094	33.7566	39.1006
261	14.7	33.7868	41.8706	33.8016	41.8738
262	17.9	34.0445	40.3302	34.0496	40.3096
263	17.9	34.2945	38.8219	34.2864	38.8026
264	15.7	+34.3237	+39.6829	+34.3404	+39.6876
265	16.8	34.3805	37.1104	34.4086	37.1098
266	15.7	34.5262	37.9874	34.5288	37.9994
267	13.3	34.6315	38.1654	34.6538	38.1728
268	17.1	35.6580	41.3244	35.6576	41.3521
269	14.7	+35.6752	+40.9629	+35.6778	+40.9648
270	14.7	35.7848	41.7209	35.8026	41.7141
271	14.7	35.8545	39.4326	35.8698	39.4401
272	17.9	35.9852	44.0179	36.0131	44.8716
273	16.8	36.2485	44.9019	36.2701	44.9214

TABLE 14

SECTION II REDUCED COORDINATES — CONTINUED

NO.	PLATE III		PLATE V		V_X	V_Y
	X	Y	X	Y	V−III	V−III
	″	″	″	″	″	″
240	+2012.24	+2198.96	+2011.91	+2198.00	−0.33	−0.96
241	2022.70	2686.68	2022.13	2686.35	−0.57	−0.33
242	2033.37	2224.93	2033.46	2224.30	+0.09	−0.63
243	2033.70	2192.55	2033.58	2193.41	−0.12	+0.86
244	2045.26	2137.80	2045.44	2138.26	+0.18	+0.46
245	+2047.53	+2154.49	+2047.08	+2153.54	−0.45	−0.95
45	2051.14	1906.76	2050.80	1907.58	−0.34	+0.82
246			2057.31	2212.01		
247	2067.39	2207.06	2066.72	2208.09	−0.67	+1.03
248	2084.47	2208.91	2084.51	2209.07	+0.04	+0.16

SECTION III. REDUCED COORDINATES

249	+1153.28	+1646.97	+1153.22	+1647.21	−0.06	+0.24
250	1153.51	1676.73	1154.21	1677.57	+0.70	+0.84
251	1188.66	1483.60	1188.33	1483.81	−0.33	+0.21
252	1208.24	1662.84	1208.80	1660.99	+0.56	−1.85
253	1214.81	1482.60	1215.49	1482.44	+0.68	−0.16
254	+1222.82	+1621.46	+1222.11	+1621.93	−0.71	+0.47
255	1233.52	1725.80	1233.44	1726.30	−0.08	+0.50
256	1245.66	1773.61	1245.61	1773.69	−0.05	+0.08
257	1247.08	1726.15	1247.35	1725.30	+0.27	−0.76
258	1248.26	1536.08	1248.58	1536.09	+0.32	+0.01
259	+1257.16	+1382.20	+	+		
260	1280.72	1488.52	1280.54	1486.88	−0.18	−1.64
261	1281.96	1589.42	1282.25	1589.75	+0.29	+0.33
262	1291.74	1531.03	1291.65	1530.46	−0.09	−0.57
263	1301.23	1473.86	1300.63	1473.34	−0.60	−0.52
264	+1302.33	+1506.51	+1302.91	+1506.90	+0.58	+0.39
265	1304.49	1408.98	1305.26	1409.17	+0.77	+0.19
266	1310.02	1442.24	1309.82	1442.91	−0.20	+0.67
267	1314.01	1448.99	1314.56	1449.49	+0.55	+0.50
268	1352.94	1568.83	1352.65	1570.08	−0.29	+1.25
269	+1353.59	+1555.13	+1353.42	+1555.40	−0.17	+0.27
270	1357.75	1583.87	1358.15	1583.81	+0.40	−0.06
271	1360.40	1497.12	1360.69	1497.61	+0.29	+0.49
272	1365.34	1705.10	1366.15	1703.53	+0.81	−1.57
273	1375.33	1704.51	1375.90	1705.44	+0.57	+0.93

TABLE 14

SECTION III. MEASURED COORDINATES — CONTINUED

NO.	MAG.	PLATE III		PLATE V	
		x	y	x	y
		r	r	r	r
274	19.0	+37.0872	+37.7244	+37.1098	+37.7464
275	13.5	37.4625	39.4592	37.4831	39.4544
276	17.3	37.5532	37.5936	37.5594	37.5868
277	14.5	38.3937	41.7574	38.3994	41.7618
278	13.7	38.7070	37.8429	38.7313	37.8528
279	15.5	+38.7488	+38.8422	+38.7516	+38.8404
280	17.9	39.3992	45.8224	39.4446	45.8198
281	14.7	39.6925	40.2979	39.6958	40.3156
282	17.9	39.8870	43.7206	39.8888	43.7044
283	17.9	40.6880	37.4739		
284	17.9	+40.8155	+44.1409	+40.8181	+44.1408
285	19.0	40.8670	42.9936		
286	14.7	41.5198	45.0712	41.5278	45.0458
287	19.0	41.6125	36.7272	41.6064	36.6874
288	16.2	42.0542	37.7920	42.0030*	37.8515*
289	12.2	+42.3620	+36.0976	+42.3806	+36.0988
290	16.8	42.3948	43.1109	42.4011	43.0692
291	14.7	42.4872	44.7254	42.4851	44.7248
292	12.8	42.6105	43.4256	42.6281	43.4431
293	17.7	43.3048	38.3122	43.2671	38.2834
294	14.5	+43.4238	+35.5744	+43.4261	+35.5626
295	17.9	43.4890	39.4256	43.5094	39.3838
296	17.3	43.7245	44.3494	43.7394	44.3636
297	14.3	43.7745	45.9174	43.7778	45.9146
298	17.9	44.1067	38.4704	44.0734	38.4586
299	15.7	+45.1002	+42.8789	+45.1034	+42.8858
300	16.2	45.2927	36.4929	45.3094	36.4871
301	16.8	45.3602	40.6549	45.3406	40.6696
302	16.8	45.4480	43.3739	45.4676	43.4046
303	16.8	45.6815	43.4759	45.6921	43.4914
304	15.7	+45.7388	+40.9022	+45.7292	+40.8824
305	14.5	45.9030	36.6324	45.9124	36.6294
306	17.0	45.9955	40.6549	46.0192	40.6348
307	17.5	46.2610	43.7322	46.2696	43.7188
308	14.0	46.4358	36.4179	46.4491	36.4156
309	19.0	+46.8202	+44.5542	+46.8054	+44.5166
310	15.7	46.9878	42.6126	46.9778	42.6141
311	17.9	47.0330	36.8206	47.0681	36.8231
312	16.8	47.0855	42.3089	47.0928	42.3304
313	13.7	47.4336*	34.6451*	47.4310*	34.6898*

*Measured and reduced with Section XIII.

TABLE 14

SECTION III. REDUCED COORDINATES — CONTINUED

NO.	PLATE III		PLATE V		V_X	V_Y
	X	Y	X	Y	V−III	V−III
	″	″	″	″	″	″
274	+1407.15	+1432.43	+1407.72	+1433.47	+0.57	+1.04
275	1421.39	1498.23	1421.89	1498.25	+0.50	+0.02
276	1424.83	1427.50	1424.77	1427.45	−0.06	−0.05
277	1456.70	1585.42	1456.65	1585.78	−0.05	+0.36
278	1468.59	1437.03	1469.23	1437.61	+0.64	+0.58
279	+1470.18	+1474.92	+1470.00	+1475.05	−0.18	+0.13
280	1494.83	1739.61	1496.32	1739.69	+1.49	+0.08
281	1505.97	1530.17	1505.82	1531.03	−0.15	+0.86
282	1513.34	1660.30	1513.16	1659.52	−0.18	−0.78
283	1543.73	1423.17				
284	+1548.56	+1675.95	+1548.41	+1676.12	−0.15	+0.17
285	1550.51	1632.45				
286	1575.27	1711.27	1575.33	1710.47	+0.06	−0.80
287	1578.80	1394.02	1578.28	1393.00	−0.52	−1.32
288	1595.55	1435.35	1595.81	1435.35	+0.26	0.00
289	+1607.23	+1371.09	+1607.64	+1371.33	+0.41	+0.24
290	1608.46	1637.00	1608.45	1635.59	−0.01	−1.41
291	1611.96	1698.22	1611.64	1698.36	−0.32	+0.14
292	1616.64	1648.95	1617.06	1649.78	+0.42	+0.83
293	1642.90	1455.12	1641.28	1454.21	−1.71	−0.91
294	1647.50	1351.33	1647.30	1351.07	−0.20	−0.26
295	1649.97	1497.35	1650.47	1495.94	+0.50	−1.41
296	1658.89	1684.04	1659.22	1684.75	+0.33	+0.71
297	1660.79	1743.50	1660.68	1743.55	−0.11	+0.05
298	1673.40	1461.17	1671.86	1460.90	−1.54	−0.27
299	1711.08	1628.38	1710.95	1628.81	−0.13	+0.43
300	1718.39	1386.27	1718.74	1380.23	+0.35	−0.04
301	1720.94	1544.08	1719.94	1544.80	−1.00	+0.72
302	1724.27	1647.17	1724.77	1648.50	+0.50	+1.33
303	1733.12	1651.05	1733.28	1651.80	+0.16	+0.75
304	1735.30	1553.48	1734.68	1552.89	−0.62	−0.59
305	1741.54	1391.60	1741.61	1391.67	+0.07	+0.27
306	1745.04	1544.12	1745.68	1543.52	+0.64	−0.60
307	1755.10	1660.81	1755.19	1660.46	+0.09	−0.35
308	1761.75	1383.50	1761.97	1383.59	+0.22	+0.09
309	1776.31	1692.01	1775.52	1690.73	−0.79	−1.28
310	1782.67	1618.41	1782.05	1618.62	−0.62	+0.21
311	1784.40	1390.15	1785.45	1399.08	+1.05	−0.07
312	1786.38	1606.90	1786.41	1607.87	+0.03	+0.97
313	1801.00	1314.00	1801.50	1315.30	+0.50	+1.30

TABLE 14

SECTION III. MEASURED COORDINATES—CONTINUED

NO.	MAG.	PLATE III		PLATE V	
		x	y	x	y
		r	r	r	r
314	16.8	+47.5420	+43.0536	+47.5431	+43.0236
315	16.8	47.9535	43.6156	47.9576	43.5658
316	14.6	48.2340	35.4746	48.2344	35.4559
317	16.8	48.2500	43.8916	48.2848	43.8884
318	16.8	48.4130	37.4915	48.4314	37.4908
319	19.0	+48.6248	+39.9874	+48.6618	+39.9324
320	16.2	48.7806*	47.1263*	48.7670*	47.1292*
321	15.7	49.0358	45.8132	49.0378	45.8218
322	17.9	49.1178	42.3686	49.1301	42.3504
323	16.8	49.1722	46.4556	48.8466	47.0904
324	15.2	+49.3605	+40.6074	+49.3708	+40.5928
325	16.8	49.3845	37.9714	49.3684	37.9431
326	16.8	49.5637	45.4104	49.5824	45.4051
327	16.5	49.5665	41.9204	49.5464	41.9064
328	16.5	49.8792	42.9419	49.8964	42.9258
329	13.5	+50.4622	+42.2162	+50.4566	+42.2134
330	15.7	50.7480	44.7854	50.7686	44.7906
331	10.9	50.8310	39.5139	50.8306	39.5214
332	14.7	50.8970	42.6444	50.9144	42.6366
333	17.9	51.0142	44.6942	51.0301	44.6908
334	16.2	+51.7825	+40.2874	+51.7974	+40.2856
335	17.9	51.7862	39.6886	51.7908	39.6524
336	14.3	51.9448	37.6484	51.9516	37.6614
337	16.4	53.7062	35.5359	53.7226	35.5401
338	16.8	53.8338	37.2792	53.8636	37.2808
339	14.5	+53.9935	+35.6529	+54.0134	+35.6658
340	15.7	54.1315	39.0712	54.1438	39.0666
341	17.3	54.4960	35.8566	54.5094	35.8366

*Measured and reduced with Section XIII.

SECTION IV. MEASURED COORDINATES

342	15.5	+ 8.9728	+41.0134	+ 8.9938	+40.9988
343	16.2	9.9185	41.6528	9.9140	41.6362
344	16.8	10.1610	41.6191	10.1435	41.6060
345	14.1	10.7918	44.7658	10.7900	44.7452
346	15.7	10.8718	42.5941	10.8628	42.5822

TABLE 14

SECTION III. REDUCED COORDINATES — Continued

NO.	PLATE III		PLATE V		V_X	V_Y
	X	Y	X	Y	V − III	V − III
	″	″	″	″	″	″
314	1803.69	1635.16	1803.49	1634.18	−0.20	−0.98
315	1819.30	1656.50	1819.22	1654.76	−0.08	−1.74
316	1829.96	1347.85	1829.68	1347.32	−0.28	−0.53
317	1830.55	1666.98	1831.63	1667.01	+1.08	+0.03
318	1836.74	1424.23	1837.16	1424.48	+0.42	+0.25
319	1844.77	1518.98	1845.91	1517.06	+1.14	−1.92
320	1852.47	1787.41	1852.99	1787.15	+0.52	−0.26
321	1860.35	1739.89	1860.20	1740.35	−0.15	+0.46
322	1863.46	1609.29	1863.69	1608.75	+0.23	−0.54
323	1865.52	1764.25				
324	1872.67	1542.53	1872.81	1542.14	+0.14	−0.39
325	1873.59	1442.59	1872.71	1441.68	−0.88	−0.91
326	1880.37	1724.65	1880.86	1724.59	+0.49	−0.06
327	1880.48	1592.33	1879.48	1591.95	−1.00	−0.38
328	1892.34	1631.08	1892.76	1630.62	+0.42	−0.46
329	1914.46	1603.60	1914.00	1603.64	−0.46	+0.04
330	1925.29	1701.03	1925.85	1701.37	+0.56	+0.34
331	1928.45	1501.17	1928.18	1501.61	−0.27	+0.44
332	1930.95	1619.86	1931.37	1619.71	+0.42	−0.15
333	1935.39	1697.59	1935.77	1697.60	+0.38	+0.01
334	1964.54	1530.56	1964.85	1530.64	+0.31	+0.08
335	1964.68	1507.86	1964.60	1506.63	−0.08	−1.23
336	1970.70	1430.51	1970.69	1431.16	−0.01	+0.65
337	2037.51	1350.53	2037.86	1350.85	+0.35	+0.32
338	2042.35	1416.64	2043.21	1416.85	+0.86	+0.21
339	2048.41	1354.99	2048.89	1355.63	+0.48	+0.64
340	2053.64	1484.60	2053.85	1484.57	+0.21	−0.03
341	2067.47	1362.74	2067.70	1362.14	+0.23	−0.60

SECTION IV. REDUCED COORDINATES

342	+ 340.72	+1555.56	+ 341.49	+1555.58	+0.77	+0.02
343	376.59	1579.85	376.40	1579.79	−0.19	−0.06
344	385.79	1578.58	385.11	1578.66	−0.68	+0.08
345	409.71	1697.93	409.66	1697.74	−0.05	−0.19
346	412.75	1615.62	412.40	1615.71	−0.35	+0.09

TABLE 14

SECTION IV. MEASURED COORDINATES — CONTINUED

NO.	MAG.	PLATE III		PLATE V	
		x	y	x	y
		r	r	r	r
347	15.5	+11.4318	+51.3654	+11.4135	+51.3592
348	14.2	11.7042	51.6618	11.7062	51.6452
349	11.2	11.8930	41.4101	11.9045	41.3985
350	15.7	12.5558	37.8866	12.5522	37.8600
351	14.3	12.6235	46.3231	12.6292	46.3192
352	13.9	+12.8785	+37.9901	+12.8875	+37.9690
353	16.8	13.2532	47.7921	13.2482	47.7948
354	14.9	13.8588	38.8294	13.8632	38.8095
355	13.3	14.2212	47.2008	14.2302	47.1945
356	14.7	14.4720	40.9386	14.4800	40.9350
357	15.1	+14.5573	+46.4436	+14.5562	+46.4425
358	15.3	14.7810	47.6196	14.7875	47.6172
359	14.5	15.7838	47.2371	15.7915	47.2238
360	10.8	15.7952	50.6954	15.7918	50.6835
361	15.0	16.2328	46.2296	16.2380	46.2205
362	15.5	+16.2990	+51.2931	+16.2882	+51.2740
363	11.2	16.8435	46.4636	16.8560	46.4595
364	14.0	16.9562	44.5203	16.9655	44.5178
365	15.7	17.0808	49.5591	17.0888	49.5342
366	13.3	17.3462	50.8484	17.3548	50.8525
367	13.7	+17.4372	+41.2898	+17.4477	+41.2890
368	15.7	17.4778	45.5541	17.4742	45.5432
369	16.2	17.7348	52.8838	17.7370	52.8672
370	15.2	17.9932	37.3431	18.0026	37.3130
371	14.2	18.0448	37.8196	18.0505	37.8105
372	13.3	+18.1525	+49.9791	+18.1522	+49.9608
373	15.7	18.4732	36.1564	18.4785	36.1415
374	16.6	18.5885	35.9724	18.5952	35.9538
375	12.3	19.2230	53.4641	19.2148	53.4652
376	16.3	19.8572	35.7913	18.8452	35.7827
377	13.5	+19.9055	+43.4946	+19.9220	+43.4980
378	16.2	20.1170	45.2408	20.1355	45.2152
379	13.7	20.6814	49.2401	20.6800	49.2182
37	10.4	20.8082	51.0274	20.7920	51.0230
380	12.8	21.2205	44.2968	21.2185	44.2870
381	15.5	+21.5272	+50.8441	+21.5230	+50.8335
382	15.9	21.9820	42.4368	22.0132	42.4310
383	16.8	22.0149	45.8811	22.0502	45.8435
384	13.5	22.2700	45.0651	22.2775	45.0528
385	14.5	22.8910	46.7428	22.9032	46.7350

TABLE 14

SECTION IV. REDUCED COORDINATES — CONTINUED

NO.	PLATE III		PLATE V		V_X	V_Y
	X	Y	X	Y	V − III	V − III
	″	″	″	″	″	″
347	+ 433.96	+1948.20	+ 433.37	+1948.60	−0.59	+0.40
348	444.29	1959.46	444.48	1959.46	+0.19	0.00
349	451.50	1570.74	451.91	1570.85	+0.41	+0.11
350	476.67	1437.16	476.45	1436.68	−0.22	−0.48
351	479.19	1757.06	479.44	1757.50	+0.25	+0.44
352	+ 488.91	+1441.10	+ 489.17	+1440.82	+0.26	−0.28
353	503.08	1812.80	502.94	1813.49	−0.14	+0.69
354	526.10	1472.97	526.19	1472.74	+0.09	−0.23
355	539.80	1790.42	540.18	1790.76	+0.38	+0.34
356	549.35	1552.98	549.60	1553.37	+0.25	+0.39
357	+ 552.50	+1761.72	+ 552.54	+1762.25	−0.02	+0.53
358	561.04	1806.33	561.33	1806.81	+0.29	+0.48
359	509.09	1791.87	509.41	1791.93	+0.32	+0.06
360	599.50	1923.00	599.45	1923.14	−0.05	+0.14
361	616.13	1753.69	616.34	1753.89	+0.21	+0.20
362	+ 618.61	+1945.69	+ 618.28	+1945.55	−0.33	−0.14
363	639.30	1762.59	639.78	1762.98	+0.48	+0.39
364	643.58	1688.91	643.92	1689.35	+0.34	+0.44
365	648.28	1879.98	648.64	1879.60	+0.36	−0.38
366	658.34	1928.88	658.74	1929.61	+0.40	+0.73
367	+ 661.85	+1566.44	+ 662.18	+1566.91	+0.33	+0.47
368	663.37	1728.13	663.22	1728.25	−0.15	+0.12
369	673.08	2006.08	673.26	2006.03	+0.18	−0.05
370	682.96	1416.81	683.20	1416.14	+0.24	−0.67
371	684.92	1434.88	685.30	1435.01	+0.44	+0.13
372	+ 688.94	+1895.95	+ 688.98	+1895.82	+0.04	−0.13
373	701.18	1371.83	701.24	1371.73	+0.06	−0.10
374	705.55	1364.86	705.66	1364.61	+0.11	−0.25
375	729.54	2028.15	729.32	2028.77	−0.22	+0.62
376	715.75	1358.01	715.14	1358.13	−0.61	+0.12
377	+ 755.48	+1650.16	+ 756.06	+1650.78	+0.58	+0.62
378	763.50	1716.38	764.17	1715.92	+0.67	−0.46
379	784.89	1868.05	784.86	1867.75	−0.03	−0.30
37	789.69	1035.83	789.13	1936.21	−0.56	+0.38
380	805.37	1680.64	805.25	1680.75	−0.12	+0.11
381	+ 816.97	+1028.91	+ 816.86	+1929.05	−0.11	+0.14
382	834.27	1610.14	835.38	1610.39	+1.11	+0.25
383	835.50	1740.75	836.81	1739.82	+1.31	−0.93
384	845.18	1709.82	845.43	1709.84	+0.25	+0.02
385	868.73	1773.46	869.18	1773.66	+0.45	+0.20

TABLE 14

SECTION IV. MEASURED COORDINATES — Continued

NO.	MAG.	PLATE III		PLATE V	
		x	y	x	y
		r	r	r	r
386	14.7	+23.3995	+47.5898	+23.4045	+47.5718
387	15.7	23.8695	54.2956	23.8485	54.2655
388	14.9	24.4145	50.8756	24.4045	50.8455
389	13.3	25.5902	40.9386	25.6015	40.9325
390	15.9	25.8160*	36.6819*	25.9005	36.6615
391	12.5	+26.0030	+45.4891	+26.0163	+45.4870
392	16.8	27.2880	42.7198	27.2862	42.7210
393	14.2	27.8375	47.3798	27.8375	47.3850

*Measured and reduced with Section XIII.

SECTION V. MEASURED COORDINATES

394	19.0	−14.7492	+21.7762	−14.7466	+21.7466
395	16.2	14.5052	22.5180	14.5813	22.4741
396	17.3	13.5894	23.4088	13.6244	23.3494
397	17.0	13.5266	20.1042	13.5401	20.0398
398	16.8	13.1446	23.9815	13.1854	23.9728
399	11.9	−11.0414	+22.7710	−11.0414	+22.7351
400	17.0	8.9476	20.4412	8.9471	20.4068
401	13.5	8.9176	19.6045	8.8981	19.5798
402	17.6	8.8282	24.4000	8.8524	24.3751
403	17.6	8.7016	18.3082	8.7344	18.3728
404	14.2	− 6.8527	+19.7855	− 6.8646	+19.7724
405	10.2	6.4864	21.1240	6.5098	21.1064
406	13.7	6.3022	19.9740	6.3198	19.9516
407	17.1	3.9816	23.0380	3.9874	23.0096
408	16.8	3.7702	21.5252	3.7751	21.4836
409	17.9	− 1.0464	+24.3275	− 1.0641	+24.3066
410	16.5	+ 0.1142	22.7272	+ 0.1042	22.7131
411	10.8	0.6666	20.5322	0.6696	20.5158
412	11.9	2.5628	20.6137	2.5674	20.6074
413	12.8	2.9263	19.1502	2.9259	19.1516
414	14.7	+ 3.2436	+19.3932	+ 3.2496	+19.3666
415	16.2	5.5808	19.7122	5.5964	19.7011
416	14.7	7.8121	26.2235	7.7864	26.2158
417	14.9	8.0386	20.3900	8.0482	20.3681
418	17.1	8.1681	23.3235	8.1612	23.3044
419	15.2	+ 8.8011	+21.3337		
420	16.8	8.8756	20.1435	+ 8.8694	+20.1354
421	13.3	9.7486	22.5657	9.7456	22.5778
422	13.3	9.7628	26.0840	9.7539	26.0816
423	14.7	9.9754	23.5177	9.9646	23.4941

TABLE 14
SECTION IV. REDUCED COORDINATES—CONTINUED

NO.	PLATE III		PLATE V		V_X	V_Y
	X	Y	X	Y	V−III	V−III
	″	″	″	″	″	″
386	+ 888.02	+1805.00	+ 888.20	+1805.42	+0.18	−0.18
387	905.81	2059.90	905.10	2059.30	−0.71	−0.60
388	926.51	1930.24	926.16	1929.61	−0.35	−0.63
389	971.17	1553.50	971.48	1553.70	+0.31	+0.20
390	980.98	1391.26	983.13	1391.73	+2.15	+0.47
391	+ 986.80	+1726.07	+ 987.26	+1726.45	+0.46	+0.38
392	1035.57	1621.12	1035.41	1621.59	−0.16	+0.47
393	1056.39	1797.85	1056.36	1798.50	−0.03	+0.65

SECTION V. REDUCED COORDINATES

394	− 559.34	+ 824.34	− 559.03	+ 824.50	+0.31	+0.16
395	552.38	852.47	552.75	853.10	−0.37	+0.63
396	515.39	886.31	516.45	885.32	−1.06	−0.99
397	512.03	761.03	513.29	759.82	−0.36	−1.21
398	498.53	908.06	499.79	908.98	−1.26	+0.92
399	− 418.74	+ 862.31	− 418.48	+ 862.12	+0.26	−0.19
400	339.27	774.12	339.07	773.91	+0.20	−0.21
401	338.11	742.39	337.22	742.55	+0.89	+0.16
402	334.84	924.22	335.43	924.39	−0.59	+0.17
403	329.89	696.67	331.03	696.78	−1.14	+0.11
404	− 259.80	+ 749.40	− 260.09	+ 749.92	−0.29	+0.52
405	245.94	800.17	246.61	800.52	−0.67	+0.35
406	238.93	756.58	239.42	756.74	−0.49	+0.16
407	150.99	872.91	150.92	872.79	+0.07	−0.12
408	142.93	815.57	142.88	814.93	+0.05	−0.64
409	− 39.69	+ 922.00	− 40.02	+ 922.08	−0.33	+0.08
410	+ 4.36	861.40	+ 4.28	861.69	−0.08	+0.29
411	25.37	778.22	25.70	778.39	+0.33	+0.17
412	97.28	781.44	97.68	781.93	+0.40	+0.49
413	111.10	725.97	111.26	726.74	+0.16	+0.77
414	+ 123.13	+ 735.21	+ 123.54	+ 734.90	+0.41	−0.31
415	211.77	747.46	212.56	747.67	+0.79	+0.21
416	296.24	994.48	295.71	994.80	−0.53	+0.32
417	304.97	773.33	305.57	773.05	+0.60	−0.28
418	309.81	884.57	309.89	884.41	+0.08	−0.16
419	+ 333.86	+ 809.16				
420	336.72	764.04	+ 336.71	+ 764.26	−0.01	+0.22
421	369.77	855.03	369.98	856.91	+0.21	+0.98
422	370.23	989.33	370.33	989.78	+0.10	+0.45
423	378.35	892.04	378.30	891.67	−0.05	−0.37

TABLE 14

SECTION V. MEASURED COORDINATES — CONTINUED

NO.	MAG.	PLATE III		PLATE V	
		x	y	x	y
		r	r	r	r
424	14.7	+10.8224	+25.4185	+10.8079	+25.4111
425	11.3	13.0361	23.4745	13.0044	23.4846
426	15.7	13.1624	25.8028	13.1700	25.7871
427	14.3	14.0742	22.7675	14.0702	22.7771
428	16.5	14.1738	21.4898	14.1694	21.4856
429	14.9	+15.0828	+23.9665	+15.0719	+23.9638
430	16.2	15.3056	25.6248	15.2914	25.6108
431	15.5	15.3601	26.1565	15.3509	26.1541
432	17.9	15.6668	24.5570	15.6876	24.5516
433	16.8	15.8006	26.0768	15.7719	26.0461
434	13.0	+15.9278	+22.7608	+15.9229	+22.7521
435	11.6	16.2411	21.7390	16.2322	21.7323
436	11.9	16.3914	23.1350	16.3759	23.1423
437	14.7	16.4922	21.9830	16.4849	21.9711
438	16.2	17.9768	22.5058	17.9769	22.4904
439	17.9	+18.8776	+21.9475	+18.8806	+21.9358
440	17.9	19.0596	22.7057	19.0386	22.6958
441	17.6	19.0926	22.9838	19.0961	22.9911
442	16.0	19.6896	22.2715	19.6876	22.2588
443	15.4	20.2866	26.0085	20.2479	26.8866
444	16.8	+20.7588	+23.1677	+20.7522	+23.1471
445	18.4	20.9106	22.6245	20.8976	22.6376
446	16.5	21.0278	22.9652	21.0072	22.9506
447	14.2	21.3906	22.8135	21.3864	22.8101
448		21.9076	26.4272		
449	11.7	+22.5038	+25.4070	+22.4886	+25.4126
450	13.5	22.6138	24.0548	22.6076	24.0628
451	15.2	22.9454	26.5108	22.9186	26.5058
452	10.5	23.4334	22.2372	23.4239	22.2546
453	16.8	23.7568	23.5532	23.7762	23.5454
454	14.7	+23.8566	+24.6808	+23.8452	+24.6773
455	14.9	25.4064	25.6305	25.4020	25.6356
456	15.2	25.8538	22.9628	25.8396	22.9481
457	14.2	26.1424	24.6535	26.1319	24.6716
458	16.5	26.9516	24.6172	26.9539	24.5878
459	16.8	+27.1834	+24.2310	+27.1662	+24.2256
460		29.5636	21.7148		
461	17.9	29.6841	25.6932	29.6714	25.6936
462	14.7	29.9646	22.4260	29.9636	22.4326

TABLE 14

SECTION V. REDUCED COORDINATES — CONTINUED

NO.	PLATE III		PLATE V		V_X	V_Y
	X	Y	X	Y	V − III	V − III
	″	″	″	″	″	″
424	+ 410.43	+ 964.17	+ 410.31	+ 964.39	−0.12	+0.22
425	404.43	890.61	493.60	891.41	−0.83	+0.80
426	499.17	978.89	499.91	978.73	+0.74	−0.16
427	533.82	863.88	534.01	864.62	+0.19	+0.74
428	537.03	815.44	537.76	815.65	+0.13	+0.21
429	+ 572.05	+ 909.40	+ 572.02	+ 909.66	−0.03	+0.26
430	580.46	972.29	580.37	972.13	−0.09	−0.16
431	582.51	902.45	582.63	902.73	+0.12	+0.28
432	594.18	931.83	595.38	931.97	+1.20	+0.14
433	599.22	989.46	598.60	988.65	−0.62	−0.81
434	+ 604.12	+ 863.75	+ 604.29	+ 863.74	+0.17	−0.01
435	616.03	825.03	616.01	825.08	−0.02	+0.05
436	621.70	877.97	621.47	878.56	−0.23	+0.59
437	625.55	834.30	625.59	834.15	+0.04	−0.15
438	681.84	854.22	682.19	853.89	+0.35	−0.33
439	+ 716.02	+ 833.11	+ 716.46	+ 832.90	+0.44	−0.21
440	722.91	861.87	722.47	861.72	−0.44	−0.15
441	724.15	872.42	724.65	872.92	+0.50	+0.50
442	746.81	845.45	747.08	845.17	+0.27	−0.28
443	769.34	1021.30	768.39	1020.69	−0.95	−0.61
444	+ 787.34	+ 879.50	+ 787.47	+ 878.90	+0.13	−0.60
445	793.11	858.92	792.98	859.58	−0.13	+0.66
446	797.55	871.84	797.14	871.68	−0.41	−0.16
447	811.31	866.12	811.52	866.14	+0.21	+0.02
448	830.83	1003.16				
449	+ 853.47	+ 964.52	+ 853.36	+ 964.87	−0.11	+0.35
450	857.67	913.26	857.86	913.69	+0.19	+0.43
451	870.19	1006.40	869.68	1006.34	−0.51	−0.06
452	888.80	844.40	888.80	845.15	0.00	+0.75
453	901.04	894.32	902.18	894.11	+1.14	−0.21
454	+ 904.79	+ 937.08	+ 904.81	+ 937.04	+0.02	−0.04
455	963.55	973.19	963.87	973.43	+0.32	+0.24
456	980.58	872.08	980.43	871.53	−0.15	−0.55
457	991.49	936.20	991.54	936.90	+0.05	+0.70
458	1022.18	934.88	1022.72	933.75	+0.54	−1.13
459	+1030.98	+ 920.25	+1030.77	+ 920.03	−0.21	−0.22
460	1121.31	825.01				
461	1125.79	975.86	1125.81	975.79	+0.02	−0.07
462	1136.51	852.01	1136.85	852.14	+0.34	+0.13

TABLE 14

SECTION VI. MEASURED COORDINATES

NO.	MAG.	PLATE III		PLATE V	
		x	y	x	y
		r	r	r	r
463	16.0	−17.5522	+29.6862	−17.5512	+29.6614
464	15.5	16.9439	30.6390	16.9672	30.5899
465	14.0	16.9034	29.5215	16.9335	29.5049
466	16.2	16.6992	27.0998	16.7332	27.0600
467	19.0	16.4962	28.8926		
468	17.8	−16.1689	+26.3710	−16.2015	+26.3329
469	17.8	15.9432	30.0210		
470	16.4	14.2624	29.0943	−14.2822	29.0896
471	17.9	13.4076	29.8851	13.4197	29.8716
472	17.3	13.1796	25.9468	13.1965	25.8887
473	16.1	−11.6982	+28.8560	−11.7125	+28.8222
474	16.5	11.2012	29.2525	11.2158	29.1932
475	14.4	11.1879	29.0432	11.2020	29.0020
476	16.8	10.9972	27.4732	11.0095	27.4229
477		10.6024	30.0215		
478	14.4	− 9.6114	+32.4963		
479	16.0	9.5504	28.7305	− 9.5672	+28.6814
480	16.0	8.9242	30.0712	8.9767	30.0278
481	13.9	8.3592	25.2437	8.3792	25.2282
482	15.0	8.1762	32.7395	8.2298*	32.6860*
483	16.2	− 7.3579	+28.6775	− 7.4060	+28.6594
484	19.0	6.8484	30.0090	6.8795	29.9839
485	14.2	6.7262	24.5520	6.7345	24.5332
486	15.7	6.3672	29.4176	6.3808	29.3672
487	13.3	6.3376	25.0205	6.3408	25.0132
488	11.9	− 5.9834	+25.7884	− 5.9902	+25.7764
489	16.2	6.1227	29.7318	6.1355	29.7046
490	13.9	5.5496	26.2900	5.5728	26.2621
491	11.7	4.3549	32.3058	4.4165*	32.3338*
492	13.7	3.9684	28.2085	3.9880	28.1984
493	15.4	− 3.6894	+26.2368	− 3.6895	+26.2221
494	15.0	3.0572	29.1635	3.0815	29.1500
495	14.7	1.6166	28.8752	1.6378	28.8636
496		0.8992	25.4777		
497	11.9	0.4446	29.9048	0.4715	29.8887
498	15.4	− 0.0886	+25.6215	− 0.1148	+25.6082
499	17.1	+ 1.0743	28.4252	+ 1.0530	28.3964
500	18.4	1.2548	31.8930	1.2510	31.8746
501	17.1	1.3428	26.5837	1.3520	26.5512
502	18.4	1.4561	32.7350	1.4362	32.7536

*Measured and reduced with Section XIII.

TABLE 14
SECTION VI. REDUCED COORDINATES

NO.	PLATE III		PLATE V		V_X	V_Y
	X	Y	X	Y	V−III	V−III
	″	″	″	″	″	″
463	− 665.79	+1124.29	− 665.17	+1124.44	+0.62	+0.15
464	642.74	1160.46	643.01	1159.68	−0.27	−0.78
465	641.18	1118.69	641.74	1118.53	−0.56	+0.44
466	633.39	1026.28	634.18	1025.82	−0.79	−0.46
467	625.73	1094.27				
468	− 613.27	+ 998.68	− 614.02	+ 998.28	−0.75	−0.40
469	604.77	1137.10				
470	541.00	1102.08	541.19	1102.90	−0.19	+0.82
471	508.59	1132.12	508.46	1132.60	+0.13	+0.48
472	499.87	982.80	500.05	981.56	−0.18	−1.24
473	− 443.74	+1093.22	− 443.73	+1092.88	+0.01	−0.34
474	424.89	1108.29	424.88	1106.97	+0.01	−1.32
475	424.38	1100.36	424.36	1099.72	+0.02	−0.64
476	417.12	1040.84	417.08	1039.84	+0.04	−1.00
477	402.19	1137.49				
478	− 364.65	+1231.40				
479	362.27	1088.61	− 362.36	+1087.63	−0.09	−0.98
480	338.54	1139.50	339.04	1138.72	−1.40	−0.78
481	317.02	956.48	317.34	956.73	−0.32	+0.25
482	310.21	1240.73	309.95	1240.47	+0.26	−0.26
483	− 279.10	+1086.76	− 280.39	+1086.90	−1.29	+0.14
484	259.80	1137.28	260.40	1137.15	−0.60	−0.13
485	255.07	930.37	254.97	930.45	+0.10	+0.08
486	241.54	1114.89	241.49	1113.78	+0.05	−1.11
487	240.34	948.10	240.03	948.67	+0.31	+0.51
488	− 226.92	+ 977.31	− 227.07	+ 977.63	−0.15	+0.32
489	232.27	1126.82	232.19	1126.59	+0.08	−0.23
490	210.47	996.36	210.89	996.07	−0.42	−0.29
491	165.27	1226.83	165.33	1227.03	+0.06	+0.20
492	150.53	1069.21	150.75	1069.57	−0.22	+0.36
493	− 139.91	+ 994.47	− 139.46	+ 994.63	+0.45	+0.16
494	115.99	1105.49	116.36	1105.73	−0.37	+0.24
495	61.34	1094.66	61.60	1094.90	−0.26	+0.24
496	34.08	965.88				
497	16.90	1133.78	17.35	1133.82	−0.45	+0.04
498	− 3.32	+ 971.39	− 3.87	+ 971.51	−0.55	+0.12
499	+ 40.74	1077.79	+ 40.45	1077.30	−0.29	−0.49
500	47.52	1209.29	48.00	1209.21	+0.48	−0.08
501	50.95	1007.98	51.77	1007.34	+0.82	−0.64
502	55.14	1241.23	55.04	1242.55	−0.10	+1.32

TABLE 14

SECTION VI. MEASURED COORDINATES — CONTINUED

NO.	MAG.	PLATE III		PLATE V	
		x	y	x	y
		r	r	r	r.
503	17.1	+ 1.5213	+27.1633	+ 1.5042	+27.1354
504	14.2	1.0351	26.3645	1.0240	26.3454
505	17.6	1.9053	32.0528	1.8835	32.0176
506	19.0	2.5318	30.1125	2.4777	30.1125
507	19.0	3.5261	32.7785		
508	13.7	+ 5.1146	+30.6910	+ 5.0932	+30.6866
509	15.2	5.5588	30.1230	5.5480	30.1114
510	17.9	6.6218	28.2677	6.5635	28.2614
511	15.7	6.6421	26.6508	6.6325	26.6469
512	17.9	6.8546	26.8408	6.8630	26.8274
513	15.5	+ 7.0891	+29.4340	+ 7.0752	+29.4216
514	13.4	7.3571	29.0665	7.3567	29.0572
416	14.7	7.7993	26.2278	7.7798	26.2196
515	17.3	8.7151	30.9370	8.6802	30.9244
516	17.9	8.7151	28.7880	8.6957	28.8126
517	11.9	+ 8.8404	+29.7908	+ 8.8240	+29.7822
518	11.6	9.0768	31.5985	9.0610	31.6074
519	18.4	10.5878	32.5065		
520	16.6	10.6301	30.9938	10.6035	30.9899
521	15.2	10.9764	29.2198	10.9635	29.2172
522	13.1	+11.4718	+32.5162	+11.4805	+32.5214
523	15.4	12.2758	27.1888	12.2757	27.1864
524	14.9	12.4938	31.5605	12.4828	31.5594
525	15.5	13.8184	27.8418	13.8135	27.8392
526	16.2	14.0511	32.4960	14.0632	32.4864
527	14.4	+16.5856	+32.9128	+16.5977	+32.9276
529	17.9	17.2008	30.1338	17.1802	30.1264
530	16.0	17.3901	29.9228	17.3788	29.9154
531	17.3	17.4791	31.1968	17.4660	31.1584
532	16.8	17.9071	28.8960	17.8845	28.9016
533	15.7	+18.0704	+29.6992	+18.0705	+29.6812
534	15.5	18.1156	27.1822	18.1110	27.1829
535	17.3	18.4371	32.8062	18.4200	32.8006
536	17.3	18.8038	32.9019	18.8222	32.9006
537	11.2	18.9464	28.5660	18.9432	28.5705
538	13.3	+19.3646	+30.8045	+19.3602	+30.8187
539	19.0	20.0448	31.0922	20.0690	31.0689
540	17.3	20.2751	30.7885	20.2672	30.7716
541	19.5	20.5108	31.0018	20.5320	30.9892
542	15.7	21.3971	32.0162	21.3911	32.0344

Star 528 was rejected, owing to uncertainty of measures.

TABLE 14

SECTION VI. REDUCED COORDINATES — CONTINUED

NO.	PLATE III		PLATE V		V_X	V_Y
	X	Y	X	Y	V−III	V−III
	″	″	″	″	″	″
503	+ 57.71	+1029.97	+ 57.55	+1029.50	−0.16	−0.47
504	62.04	999.69	62.08	999.55	+0.04	−0.14
505	72.19	1215.40	72.00	1214.66	−0.19	−0.74
506	95.99	1141.87	94.51	1142.44	−1.48	+0.57
507	133.66	1243.03				
508	+ 193.94	+1163.99	+ 193.72	+1164.33	−0.22	+0.34
509	210.80	1142.48	210.96	1142.54	+0.16	+0.06
510	251.16	1072.21	249.45	1072.43	−1.71	+0.22
511	251.95	1010.90	252.05	1011.20	+0.10	+0.30
512	260.01	1018.12	260.80	1018.06	+0.79	−0.06
513	+ 268.86	+1116.46	+ 268.88	+1116.45	+0.02	−0.01
514	279.03	1102.55	279.55	1102.64	+0.52	+0.09
416	295.85	994.94	295.56	995.05	−0.29	+0.11
515	330.51	1173.57	329.77	1173.51	−0.74	−0.06
516	330.55	1092.08	330.33	1093.42	−0.22	+1.34
517	+ 335.28	+1130.12	+ 335.21	+1130.20	−0.07	+0.08
518	344.22	1198.68	344.22	1109.43	0.00	+0.75
519	401.51	1233.21				
520	403.14	1175.86	402.72	1176.08	−0.42	+0.22
521	416.31	1108.61	416.35	1108.87	+0.04	+0.26
522	+ 435.04	+1233.64	+ 436.00	+1234.20	+0.96	+0.56
523	465.63	1031.69	466.10	1031.92	+0.47	+0.23
524	473.82	1197.48	474.01	1197.76	+0.19	+0.28
525	524.13	1056.56	524.43	1056.74	+0.30	+0.18
526	532.88	1233.06	533.96	1232.98	+1.08	−0.08
527	+ 629.00	+1249.04	+ 630.10	+1249.83	+1.10	+0.79
529	652.39	1143.71	652.16	1143.63	−0.23	−0.08
530	659.57	1135.72	659.69	1135.63	+0.12	−0.09
531	662.92	1184.04	663.01	1182.78	+0.09	−1.26
532	679.20	1096.83	678.85	1097.21	−0.35	+0.38
533	+ 685.72	+1127.29	+ 685.92	+1126.78	+0.20	−0.51
534	687.14	1031.86	687.42	1032.04	+0.28	+0.18
535	699.23	1245.13	699.22	1245.09	−0.01	−0.04
536	713.14	1248.79	714.47	1248.90	+1.33	+0.11
537	718.63	1084.39	719.01	1084.70	+0.38	+0.31
538	+ 734.45	+1169.30	+ 734.85	+1169.98	+0.40	+0.68
539	760.24	1180.25	761.74	1179.50	+1.50	−0.75
540	768.98	1168.75	769.25	1168.23	+0.27	−0.52
541	777.92	1176.86	779.30	1176.50	+1.38	−0.36
542	811.52	1215.38	811.90	1216.17	+0.38	+0.79

TABLE 14

SECTION VI. MEASURED COORDINATES — CONTINUED

NO.	MAG.	PLATE III		PLATE V	
		x	*y*	*x*	*y*
		r	*r*	*r*	*r*
543	Nova (?)	+	+	+21.8028	+32.0769
544	14.4	21.8241	29.4465	21.8215	29.4482
545	15.5	22.0796	31.7920	22.0585	31.7876
546	18.4	22.4131	33.9705	22.4008	33.9462
547	13.3	22.6981	30.8282	22.6920	30.8321
548	15.2	+25.9443	+31.9198	+25.8988*	+31.9470*
549	17.3	26.3726	33.1968		
550	17.4	26.8588	32.9892	26.8140	32.9764
551	19.0	27.3758	32.4770	27.3708	32.4629
552	17.3	27.6708	32.3318	27.6535	32.3309
553		+28.0926	+31.9022	+	+
554	15.2	29.2856	28.6742	29.2632	28.6814

*Measured and reduced with Section XIII.

SECTION VII. MEASURED COORDINATES

555	16.2	+17.1382	+20.9206	+17.1504	+20.9106
556	16.2	17.3292	15.2874	17.3227	15.2818
557	16.8	17.4252	13.5452		
558	15.1	17.7402	17.6082	17.7540	17.6111
559	15.6	17.8755	12.8154	17.8820	12.8108
560	17.1	+17.9658	+18.6669	+17.9630	+18.6738
561	16.8	18.2280	19.6476	18.2160	19.6596
562	15.3	18.7232	15.5329	18.7250	15.5228
563	17.1	19.3900	12.0752	19.3937	12.0748
564	16.8	20.0635	8.5374	20.0387	8.5191
565	17.9	+20.1272	+20.1064		
566	16.8	20.3247	20.7402	+20.3154	+20.7276
30	10.1	20.3285	19.6029	20.3330	19.6228
567	14.2	22.2690	8.3686	22.2782	8.3651
568	16.2	23.2192	19.0294	23.2154	19.0136
569	17.9	+23.3095	+14.1739		
570	15.2	23.7402	4.9389	+23.7420	+ 4.9328
571	16.2	23.9872	4.7979	23.9727	4.7846
572	14.4	23.9890	19.5609	23.9830	19.5484
573	17.9	24.1292	21.2534	24.1564	21.2421

TABLE 14

SECTION VII. REDUCED COORDINATES — CONTINUED

NO.	PLATE III		PLATE V		V_X V−III	V_Y V−III
	X	Y	X	Y		
	″	″	″	″	″	″
543	+	+	+ 827.51	+1217.80		
544	827.76	1117.98	828.19	1118.11	+0.43	+0.13
545	837.41	1206.93	837.21	1206.84	−0.20	−0.09
546	850.02	1289.56	850.22	1288.72	+0.20	−0.84
547	860.89	1170.43	861.22	1170.63	+0.33	+0.20
548	+ 984.00	+1212.05	+ 984.56	+1211.71	+0.56	−0.34
549	1000.22	1260.50				
550	1018.67	1252.66	1017.59	1252.14	−1.08	−0.52
551	1038.28	1233.28	1038.70	1232.69	+0.42	−0.59
552	1049.48	1227.79	1049.42	1227.69	−0.06	−0.10
553	+1065.48	+1211.53				
554	1110.79	1089.22	+1110.43	+1089.37	−0.36	+0.15

SECTION VII. REDUCED COORDINATES

555	+ 650.57	+ 794.26	+ 650.98	+ 793.99	+0.41	−0.27
556	657.79	580.68	657.48	580.54	−0.31	−0.14
557	661.42	514.63				
558	673.62	668.69	673.86	668.89	+0.24	+0.20
559	678.50	486.97	678.68	486.86	+0.18	−0.11
560	+ 681.96	+ 708.84	+ 681.80	+ 709.20	−0.16	+0.36
561	691.91	746.04	691.41	746.50	−0.50	+0.55
562	710.68	590.04	710.69	589.74	+0.01	−0.30
563	735.97	458.96	736.03	459.01	+0.06	+0.05
564	761.50	324.85	760.48	324.20	−1.02	−0.65
565	+ 763.98	+ 763.51				
566	771.47	787.54	+ 771.07	+ 787.17	−0.40	−0.37
36	771.61	744.42	771.73	745.27	+0.12	+0.85
567	845.18	318.53	845.45	318.45	+0.27	−0.08
568	881.29	722.79	881.09	722.28	−0.20	−0.51
569	+ 884.60	+ 538.69				
570	900.99	188.55	+ 900.97	+ 188.35	−0.02	−0.20
571	910.36	183.21	909.72	182.73	−0.64	−0.48
572	910.50	742.97	910.22	742.59	−0.28	−0.38
573	915.83	807.15	916.81	806.82	+0.98	−0.33

TABLE 14

SECTION VII. MEASURED COORDINATES — CONTINUED

NO.	MAG.	PLATE III		PLATE V	
		x	y	x	y
		r	r	r	r
574	15.5	+24.4665	+13.5219	+24.4567	+13.5201
575	17.9	25.1782	9.7786		
576	16.8	25.3475	18.8582	25.3594	18.8526
577	15.7	25.6268	10.1716	25.6372	10.1500
578	16.8	25.8592	5.9364		
579	15.7	+25.8890	+ 7.9269	+25.8787	+ 7.9254
580	14.7	26.1700	7.3466		
581	14.7	26.2998	9.4289	26.3117	9.4218
582	17.9	26.3838	9.9124	26.3794	9.8968
583	17.9	26.5000	6.4804	26.5140	6.4821
584	15.5	+26.6268	+17.5596	+26.6235	+17.5588
585	16.2	26.7750	6.1432	26.7802	6.1321
586	15.2	26.9730	14.8999	26.9790	14.8974
587	17.1	27.3058	15.7714		
588	15.2	27.3920	19.9099	27.3977	19.9001
589	17.9	+27.8455	+16.7994		
590	16.8	28.3355	5.6554	+28.3115	+ 5.6324
591	15.0	28.8227	8.0894	28.8257	8.0834
592	16.0	28.8418	16.9264	28.8307	16.9118
593	16.8	29.2797	9.5894	29.2672	9.5526
594	10.4	+29.3280	+15.9569	+29.3230	+15.9662
595	16.8	29.9100	9.4059	29.9122	9.3856
596	17.9	29.9452	8.0686		
597	15.7	30.1837	9.5454	30.1742	9.5466
598	15.0	30.5080	11.0592	30.5187	11.0604
599	15.1	+30.7018	+14.5852	+30.7074	+14.5901
600	18.0	30.8768	16.2074		
601	18.0	31.2205	15.7286	31.1950	15.7274
602	13.7	31.2895	10.5116	31.2882	10.5141
603	15.5	31.2912	17.3334	31.2822	17.3284
604	16.6	+31.5198	+14.8136	+31.5092	+14.8066
605	17.1	31.9550	15.1949	31.9340	15.2096
606	16.5	32.4532	9.1334	32.4402	9.1254
607	16.5	33.1015	7.6474	33.0837	7.6248
608	16.5	33.2345	19.7774	33.2354	19.7671
609	18.0	+33.5837	+17.1006		
610	17.9	33.6120	17.6739	33.5942	17.6504
611	15.7	33.8918	16.9669		
612	15.2	33.9450	17.2619	33.9467	17.2766
613	15.2	34.6125	12.2214	34.6150	12.2311

TABLE 14

SECTION VII. REDUCED COORDINATES — CONTINUED

NO.	PLATE III		PLATE V		V_X	V_Y
	X	Y	X	Y	V—III	V—III
	"	"	"	"	"	"
574	+ 928.59	+ 514.01	+ 928.15	+ 514.01	−0.44	0.00
575	955 58	372.10				
576	962.04	716.38	962.44	716.26	+0.40	−0.12
577	972.60	387.02	972.92	386.26	+0.32	−0.76
578	981.40	226.45				
579	+ 982.54	+ 301.92	+ 982.06	+ 301.91	−0.48	−0.01
580	993.19	279.93				
581	998.13	358.89	998.50	358.67	+0.37	−0.22
582	1001.32	377.22	1001.08	376.68	−0.24	−0.54
583	1005.71	247.10	1006.16	247.20	+0.45	+0.10
584	+1010.58	+ 667.19	+1010.30	+ 667.24	−0.19	+0.05
585	1016.14	234.32	1016.25	233.94	+0.11	−0.38
586	1023.70	566.35	1023.86	566.33	+0.16	−0.02
587	1030.33	606.99				
588	1039.02	756.33	1039.79	756.06	+0.17	−0.27
589	+1056.82	+ 638.41				
590	1075.35	215.89	+1074.35	+ 215.05	−1.00	−0.84
591	1093.85	308.19	1093.88	308.01	+0.03	−0.18
592	1094.62	643.26	1094.14	642.79	−0.48	−0.47
593	1111.20	365.09	1110.64	363.74	−0.56	−1.35
594	+1113.06	+ 606.52	+1112.81	+ 606.95	−0.25	+0.43
595	1135.11	358.15	1135.12	357.43	+0.01	−0.72
596	1136.44	307.45				
597	1145.50	363.45	1145.06	363.55	−0.44	+0.10
598	1157.81	420.86	1158.14	420.97	+0.33	+0.11
599	+1165.18	+ 554.56	+1165.33	+ 554.82	+0.15	+0.26
600	1171.83	616.08				
601	1184.87	597.94	1183.84	597.97	−1.03	+0.03
602	1187.46	400.13	1187.33	400.28	−0.13	+0.15
603	1187.56	658.79	1187.16	658.68	−0.40	−0.11
604	+1196.22	+ 563.25	+1195.75	+ 563.06	−0.47	−0.19
605	1212.73	577.73	1211.87	578.36	−0.86	+0.63
606	1231.61	347.92	1231.03	347.66	−0.58	−0.26
607	1256.20	291.60	1255.44	290.78	−0.76	−0.82
608	1261.31	751.53	1261.29	751.23	−0.02	−0.30
609	+1274.54	+ 650.05	+	+		
610	1275.62	671.78	1274.88	670.98	−0.74	−0.80
611	1286.23	644.90				
612	1288.25	656.18	1288.26	656.82	+0.01	+0.64
613	1313.55	465.08	1313.58	465.51	+0.03	+0.43

TABLE 14

SECTION VII. MEASURED COORDINATES — CONTINUED

NO.	MAG.	PLATE III		PLATE V	
		x	y	x	y
		r	r	r	r
614	14.2	+35.1952	+18.1952	+35.1967	+18.2004
615	17.7	35.4918	18.9789	35.5057	18.9976
616	11.2	35.6027	8.7646	35.5807	8.7696
617	16.8	35.8162	6.9936	35.8032	6.9721
618	16.0	35.8212	20.5494	35.8287	20.5331
619	17.9	+36.0112	+10.9409	+36.0004	+10.9386
620	16.0	36.3660	20.0372	36.3697	20.0218
621	11.6	36.4170	12.1672	36.4107	12.1736
622	14.4	36.5847	17.7189	36.5772	17.7151
623	16.5	36.7198	10 0666	36.7362	10.0558
624	16.0	+37.2288	+20.8724	+37.2140	+20.8521
625	15.2	38.1672	19.2679	38.1757	19.2621
626	15.4	38.4512	7.8119	38.4425	7.8046
627	10.6	38.6802	14.3102	38.6784	14.3181

MEASURES REPEATED FROM SECTION IA

52	10.8	+33.3932	+21.8186	+33.3850	+21.8261
75	17.9	37.8990	26.5772	37.9130	26.5684
79	12.8	38.4232	27.7934	38.4215	27.8064
83	13.2	39.3340	26.8724	39.3447	26.8674
93	11.3	41.8938	23.8996	41.9100	23.9126
95	15.2	+43.1880	+25.9409	+43.1944	+25.9231
96	16.8	43.5870	25.2396	43.5784	25.2314
97	17.9	43.7698	24.8466	43.7235	24.8294
102	15.7	46.6402	28.3332	46.6197	28.3321

MEASURES REPEATED FROM SECTION IB

114	16.2	+16.2822	+ 7.2784	+16.3020	+ 7.2514
115	15.5	16.4890	6.5549	16.5064	6.5541
116	14.0	17.0280	6.6589	17.0390	6.6641
117	15.2	17.1328	7.0989	17.1450	7.0931
125	16.0	19.7335	7.2526	19.7380	7.2504
129	14.7	+20.7902	+ 6.4356	+20.7972	+ 6.4291

TABLE 14

SECTION VII. REDUCED COORDINATES — CONTINUED

NO.	PLATE III		PLATE V		V_X V−III	V_Y V−III
	X	Y	X	Y		
	″	″	″	″	″	″
614	+1335.69	+ 691.61	+1335.69	+ 691.90	0.00	+0.29
615	1346.95	721.34	1347.42	722.14	+0.47	+0.80
616	1351.11	334.05	1350.19	334.29	−0.92	+0.24
617	1359.20	266.91	1358.62	266.13	−0.58	−0.78
618	1359.46	780.90	1359.69	780.38	+0.23	−0.52
619	+1366.62	+ 416.58	+1366.13	+ 416.55	−0.49	−0.03
620	1380.13	761.50	1380.21	761.01	+0.08	−0.49
621	1382.02	463.10	1381.71	463.40	−0.31	+0.30
622	1388.41	673.60	1388.07	673.55	−0.34	−0.05
623	1393.50	383.40	1394.04	383.11	+0.54	−0.35
624	+1412.87	+ 793.20	+1412.25	+ 792.53	−0.62	−0.67
625	1448.46	732.40	1448.73	732.27	+0.27	−0.13
626	1459.18	298.04	1458.77	297.80	−0.41	−0.24
627	1467.90	544.44	1467.77	544.81	−0.13	+0.37
			MEASURES REPEATED FROM SECTION IA			
52	+1267.34	+ 828.93	+1266.98	+ 829.32	−0.36	+0.39
75	1438.32	1009.53	1438.82	1009.32	+0.50	−0.21
79	1458.22	1055.66	1458.12	1056.29	−0.10	+0.63
83	1492.77	1020.78	1493.14	1020.71	+0.37	−0.07
93	1589.89	908.15	1590.46	908.76	+0.57	+0.61
95	+1639.00	+ 985.60	+1639.21	+ 985.05	+0.21	−0.55
96	1654.14	959.03	1653.77	958.84	−0.37	−0.19
97	1661.07	944.13	1659.27	943.60	−1.87	−0.53
102	1770.00	1076.44	1769.19	1076.53	−0.81	+0.09
			MEASURES REPEATED FROM SECTION IB			
114	+ 618.02	+ 276.97	+ 618.09	+ 275.99	+0.67	−0.98
115	625.86	249.54	626.44	249.55	+0.58	+0.01
116	646.32	253.51	646.65	253.74	+0.33	+0.23
117	650.30	270.19	650.67	270.02	+0.37	−0.17
125	748.97	276.12	749.06	276.08	+0.09	−0.04
129	+ 789.06	+ 245.18	+ 789.24	+ 244 97	+0.18	−0.21

TABLE 14

SECTION VII. MEASURED COORDINATES — CONTINUED

MEASURES REPEATED FROM SECTION V

NO.	MAG.	PLATE III		PLATE V	
		x	y	x	y
		r	r	r	r
430	16.2	+15.2892	+25.6236	+15.3042	+25.5966
431	15.5	15.3442	26.1706	15.3500	26.1551
432	17.9	15.6505	24.5416	15.6909	24.5596
435	11.6	15.7890	26.0772	15.7772	26.0481
436	11.9	16.3648	23.1354	16.3804	23.1434
447	14.2	+21.3688	+22.8114	+21.3922	+22.8134
449	11.7	22.4878	25.4094	22.4990	25.4161
450	13.5	22.5968	24.0606	22.6067	24.0614
452	10.5	23.4130	22.2446	23.4282	22.2638
456	15.2	25.8468	22.0746	25.8437	22.0501
457	14.2	+26.1290	+24.6739	+26.1387	+24.6508

MEASURES REPEATED FROM SECTION X

17	10.9	−28.4982	−19.7228	−28.4970	−19.7179
840	14.7	21.4142	19.3448	21.4098	19.3494
843	13.1	20.8785	18.8191	20.8717	18.8126
845	16.6	20.0885	17.3831	20.0813	17.3954
847	16.8	19.1455	17.5678	19.1488	17.5974
849	14.7	−18.7380	−16.7951	−18.7320	−16.7949
855	15.9	15.9050	17.1398	15.9093	17.1654
856	13.9	14.7882	17.6106	14.7713	17.6222
859	17.3	13.8298	18.9028	13.8233	18.9399
862	16.2	12.9982	19.1241	12.9848	19.1354
867	17.3	−11.1952	−19.3153	−11.2243	−19.3409
879	15.2	7.0318	17.6968	7.0305	17.7076

MEASURES REPEATED FROM SECTION XII

1116	11.7	−29.9692	−51.9414	−29.9388	−51.9546
1117	14.2	29.9360	53.4111	29.9233	53.4249
1118	15.2	29.8150	54.7166	29.7948	54.7452
1119	15.5	29.8102	53.7251	29.7983	53.7574

TABLE 14

SECTION VII. REDUCED COORDINATES — CONTINUED

MEASURES REPEATED FROM SECTION V

NO.	PLATE III		PLATE V		V_X	V_Y
	X	Y	X	Y	V—III	V—III
	″	″	″	″	″	″
430	+ 580.44	+ 972.51	+ 580.97	+ 971.61	+0.53	−0.90
431	582.53	093.20	583.05	992.79	+0.52	−0.47
432	594.48	931.50	595.63	932.30	+1.15	+0.80
435	599.40	989.73	598.92	988.75	−0.48	−0.98
436	621.24	878.21	621 78	878.63	+0 54	+0.42
447	+ 811.10	+ 866.12	+ 811.94	+ 866.30	+0.84	+0.18
449	853.57	964.67	853.96	965.04	+0.39	+0.37
450	857.70	913.53	858.03	913.67	+0.33	+0.14
452	888.66	844.70	889.19	845.54	+0.53	+0.84
456	981.01	872.47	980.85	871.66	−0.16	−0.81
457	+ 991.73	+ 936.92	+ 992.05	+ 936.50	+0.32	−0.42

MEASURES REPEATED FROM SECTION X

17	−1081.22	− 748.52	−1081.32	− 748.41	−0.10	+0.11
840	812.43	733.92	812.40	734.17	+0.03	−0.25
843	792.10	713.96	791.98	713.79	+0.12	+0.17
845	762.11	659.49	761.98	660.02	+0.13	−0.53
847	726.34	666.45	726.60	667.64	−0.26	−1.19
849	− 710.87	− 637.14	− 710.78	− 637.20	+0.09	−0.06
855	603.38	650.10	603.68	651.14	−0.30	−1.04
856	561.01	667.91	560.51	668.42	+0.50	−0.51
859	524.65	716.87	524.55	718.35	+0.10	−1.48
862	493.10	725.23	492.73	725.73	+0.37	−0.50
867	− 424.69	− 732.41	− 425.94	− 733.46	−1.25	−1.05
879	266.71	670.89	266.80	671.36	−0.09	−0.47

MEASURES REPEATED FROM SECTION XII

1116	−1137.19	−1070.19	−1136.26	−1070.90	+0.93	−0.71
1117	1135.94	2025.91	1135.69	2026.66	+0.25	−0.75
1118	1131.35	2075.41	1130.82	2076.72	+0.53	−1.31
1119	1131.17	2037.81	1130.95	2039.26	+0.22	−1.45

TABLE 14

SECTION VII. MEASURED COORDINATES — CONTINUED

MEASURES REPEATED FROM SECTION XIII

NO.	MAG.	PLATE III		PLATE V	
		x	y	x	y
		r	r	r	r
1193	15.2	−38.4400	−44.0928	−38.4330	−44.0990
1199	15.2	37.7075	43.7151	37.6990	43.7382
1201	14.5	37.5082	43.0178	37.4953	43.0189
1204	14.5	36.0422	42.6376	36.0173	42.6442
1211	15.7	35.6668	44.7181	35.6448	44.7336
1220	16.8	−35.1840	−45.3321		
1221		34.1785	43.6828	−34.1660	−43.7164
1225	15.5	33.2830	46.4776	33.2805	46.4804

SECTION VIII. MEASURED COORDINATES

628		−16.5228	+17.5211		
629	17.9	16.3905	14.7628	−16.3963	+14.7400
630		15.7422	16.8806		
631	15.0	15.5142	10.1391	15.5083	10.1290
632	15.2	15.0042	13.1764	14.9916	13.1352
633	15.2	−14.8058	+14.8041	−14.8026	+14.7975
634	16.8	13.2600	15.8088	13.2613	15.8022
635	16.0	13.2355	15.0731	13.2293	15.0525
636	14.7	12.9628	10.4131	12.9656	10.3957
637	16.8	12.8598	17.0558	12.8620	17.0485
638	14.5	−12.5355	+15.7061	−12.5265	+15.7085
639	16.8	11.9308	12.2491	11.9516	12.2282
640	14.7	11.5260	16.1031	11.5271	16.0907
641	16.8	11.4518	17.4143	11.4560	17.4112
642	16.8	11.4078	10.1243	11.3877	10.1115
643	16.2	−10.9112	+15.8308	−10.9198	+15.8069
644	15.0	10.8532	16.2716	10.8473	16.2695
645	17.9	10.1112	17.3696	10.1113	17.3557
646	15.7	9.9560	16.3661	9.9433	16.3559
647	13.2	9.8662	14.2604	9.8446	14.2717
648	17.9			− 9.8520	+12.7525
649	17.3	− 8.3842	+14.7028	8.3638	14.7089
650	17.9	7.8330	12.0331	7.8446	12.0172
651	14.3	7.7858	17.1496	7.7726	17.1482
652	16.8	6.4815	8.8964	6.5018	8.8837

TABLE 14

SECTION VII. REDUCED COORDINATES — CONTINUED

MEASURES REPEATED FROM SECTION XIII

NO.	PLATE III		PLATE V		V_X	V_Y
	X	Y	X	Y	V—III	V—III
	″	″	″	″	″	″
1103	−1458.56	−1672.92	−1458.50	−1673.37	+0.06	−0.45
1109	1430.76	1658.57	1430.65	1659.63	+0.11	−1.06
1201	1423.20	1632.12	1422.91	1632.34	+0.29	−0.22
1204	1367.57	1617.65	1366.83	1618.08	+0.74	−0.43
1211	1353.34	1696.52	1352.71	1697.29	+0.63	−0.77
1220	−1335.02	−1719.78				
1221	1296.86	1657.21	−1296.59	−1658.07	+0.27	−1.46
1225	1262.90	1763.14	1263.02	1763.45	−0.12	−0.31

SECTION VIII. REDUCED COORDINATES

628	− 620.70	+ 663.99				
629	621.69	559.41	− 621.98	+ 558.76	−0.29	−0.65
630	597.08	639.73				
631	588.46	384.13	588.32	383.94	+0.14	−0.19
632	569.10	499.31	568.70	497.92	+0.40	−1.39
633	− 561.56	+ 561.04	− 561.52	+ 560.96	+0.04	−0.08
634	502.90	599.19	503.03	599.12	−0.13	−0.07
635	501.98	571.30	501.83	570.69	+0.15	−0.61
636	491.66	394.62	491.85	394.11	−0.19	−0.51
637	487.71	646.49	487.88	646.40	−0.17	−0.09
638	− 475.41	+ 595.32	− 475.16	+ 595.59	+0.25	+0.27
639	452.49	404.27	453.37	463.64	−0.88	−0.63
640	437.11	610.41	437.24	610.13	−0.13	−0.28
641	434.29	660.13	434.53	660.20	−0.24	+0.07
642	432.65	383.72	432.00	383.39	+0.65	−0.33
643	− 413.78	+ 600.11	− 414.20	+ 599.39	−0.42	−0.72
644	411.58	616.83	411.45	616.93	+0.13	+0.10
645	383.42	658.49	383.52	658.15	−0.10	−0.34
646	377.54	620.45	377.15	620.24	+0.39	−0.21
647	374.14	540.61	373.42	541.21	+0.72	+0.60
648			− 373.72	+ 483.60		
649	− 317.91	+ 557.44	317.24	557.85	+0.67	+0.41
650	297.01	456.23	297.57	455.79	−0.56	−0.44
651	295.19	650.24	294.79	650.37	+0.40	+0.13
652	245.74	337.35	246.65	337.02	−0.91	−0.33

TABLE 14

SECTION VIII. MEASURED COORDINATES — CONTINUED

NO.	MAG.	PLATE III		PLATE V	
		x	y	x	y
		r	r	r	r
653	14.7	− 5.8190	+ 9.7936	− 5.8193	+ 9.7869
654	13.0	5.6520	13.3918	5.6220	13.3979
655	17.5	5.1330	16.4931	5.1130	16.4825
656	17.9	4.7835	12.6378	4.7986	12.6209
657	17.9	3.9090	11.8206	3.9270	11.7971
658	17.9	− 3.8280	+13.3848	− 3.8185	+13.3784
659	17.3	3.4040	14.7726	3.3866	14.7612
660	15.7	2.3550	15.7514	2.3500	15.7490
661	16.2	0.3752	15.3678	0.3675	15.4002
662	15.7	0.3490	12.3164	0.3330	12.3109
663	15.5	− 0.2380	+13.5224	− 0.2200	+13.5142
664	16.8	+ 0.0453*	15.8459*	+ 0.0737	15.8435
665	16.4	0.1080	14.9928	0.0960	14.9839
666	16.8	0.6035	9.9838	0.6670	9.9659
667	16.5	0.9478	15.2011	0.9660	15.2089
668	12.8	+1.1475	+16.6666	+1.1602	+16.6685
669	15.7	1.6280	16.2571	1.6290	16.2329
670	15.7	1.9452	14.4711	1.9487	14.4382
671	14.4	2.3358	17.8466	2.3282	17.8437
672	16.0	2.7425	16.9144	2.7567	16.9062
673	15.7	+ 4.1938	+14.0428	+ 4.1827	+14.0402
674	16.8	6.0098	12.3573	6.0470	12.3802
675	14.7	6.3570	17.6731	6.3697	17.6752
676	17.9	7.9248	16.8431	7.9607	16.8509
677	14.9	8.9568	14.4064	8.9740	14.4037
678	14.5	+ 9.2852	+15.7254	+ 9.2954	+15.7195
679	16.8	9.6142	17.7264	9.6090	17.7299
680	16.2	9.7805	12.5350	9.8057	12.5182
681	17.9	11.0535	10.6516	11.0770	10.6759
682	16.2	11.1260	10.4103		
683	14.0	+11.3275	+20.5781	+11.3500	+20.5712
684	15.7	11.4582	18.0001	11.4352	17.9889
685	16.0	11.8720	10.3504	11.8744	10.3517
686	13.1	12.2750	16.4361	12.2922	16.4492
33	11.5	13.4780	10.0601	13.4835	10.0707
687	16.8	+14.4288	+11.4316	+14.4532	+11.4415
688	14.2	14.9810	9.4214	14.9915	9.4245
689	11.4	15.0388	18.6218	15.0420	18.6297
690	14.7	15.0595	20.1268	15.0490	20.0729
691	16.5	16.2420	8.6478	16.2705	8.6582

*Measured and reduced with Section XIII

TABLE 14

SECTION VIII. REDUCED COORDINATES — CONTINUED

NO.	PLATE III		PLATE V		V_X	V_Y
	X	Y	X	Y	V − III	V − III
	″	″	″	″	″	″
653	− 220.60	+ 371.40	− 220.75	+ 371.30	−0.15	−0.10
654	214.25	507.83	213.24	508.24	+1.01	+0.41
655	194.54	625.44	193.90	625.23	+0.64	−0.21
656	181.30	479.28	182.00	478.80	−0.70	−0.48
657	148.12	448.33	148.94	447.60	−0.82	−0.73
658	− 145.04	+ 507.04	− 144.81	+ 507.56	+0.23	−0.08
659	128.94	560.27	128.42	560.02	+0.52	−0.25
660	89.14	597.43	89.09	597.52	+0.05	+0.09
661	14.02	582.96	13.88	584.36	+0.14	+1.40
662	13.04	467.26	12.59	467.22	+0.45	−0.04
663	− 8.82	+ 512.99	− 8.29	+ 512.85	+0.53	−0.14
664	+ 2.72	600.97	+ 2.86	601.19	+0.14	+0.22
665	4.31	568.76	3.70	568.60	−0.61	−0.16
666	25.36	378.85	25.33	378.33	−0.03	−0.52
667	30.18	576.09	30.71	577.16	+0.53	+0.47
668	+ 43.76	+ 632.26	+ 44.09	+ 632.52	+0.33	+0.26
669	61.99	616.75	61.87	616.02	−0.12	−0.73
670	74.02	549.05	73.99	547.97	−0.03	−1.08
671	88.86	677.05	88.41	677.13	−0.45	+0.08
672	104.28	641.72	104.66	641.59	+0.38	−0.13
673	+ 159.34	+ 532.89	+ 158.74	+ 532.96	−0.60	+0.07
674	228.23	469.05	229.45	470.09	+1.22	+1.04
675	241.43	670.62	241.73	670.89	+0.30	+0.27
676	300.91	639.21	302.09	639.69	+1.18	+0.48
677	340.06	546.86	340.51	546.93	+0.45	+0.07
678	+ 352.53	+ 596.88	+ 352.71	− 596.84	+0.18	−0.04
679	365.02	672.77	364.63	673.09	−0.39	+0.32
680	371.30	475.93	372.05	475.46	+0.75	−0.47
681	419.60	404.57	420.27	405.65	+0.67	+1.08
682	422.34	395.42				
683	+ 430.04	+ 780.96	+ 430.70	+ 780.90	+0.66	−0.06
684	434.99	683.21	433.91	682.98	−1.08	−0.23
685	450.65	393.18	450.52	393.38	−0.13	+0.20
686	465.97	623.94	466.41	624.62	+0.44	+0.68
33	511.58	382.23	511.56	382.79	−0.02	+0.56
687	+ 547.67	+ 434.27	+ 548.36	+ 434.81	+0.69	+0.54
688	568.61	358.07	568.76	358.34	+0.15	+0.27
689	570.85	706.92	570.75	707.41	−0.10	+0.49
690	571.64	763.99	571.02	762.14	−0.62	−1.85
691	616.35	328.79	617.28	329.33	+0.83	+0.54

TABLE 14

SECTION VIII. MEASURED COORDINATES — Continued

Measures Repeated from Section Ib

NO.	MAG.	PLATE III		PLATE V	
		x	y	x	y
		r	r	r	r
114	16.4	+16.2888	+ 7.2781	+16.3027	+ 7.2327
115	15.5	16.4960	6.5516	16.5092	6.5535
116	14.0	17.0235	6.6591	17.0410	6.6662

Measures Repeated from Section V

395	16.2	−14.5690	+22.4898	−14.5710	+22.4759
396	17.3	13.5925	23.3748	13.6023	23.3557
397	17.0	13.5205	20.0728	13.5393	20.0342
398	16.8	13.1282	23.9621	13.1633	23.9575
400	17.0	8.9405	20.4134	8.9393	20.4085
401	13.5	− 8.9222	+19.5818	− 8.8823	+19.5819
403	17.6	8.7058	18.3751	8.7278	18.3765
404	14.2	6.8608	19.7721	6.8570	19.7677
405	10.2	6.4020	21.0021	6.4936	21.1062
406	13.7	6.3118	19.9578	6.3138	19.9447
411	10.8	+ 0.6580	+20.5226	+ 0.6692	+20.5222
412	11.9	2.5648	20.5988	2.5662	20.6019
413	12.8	2.9192	19.1498	2.9332	19.1482

Measures Repeated From Section IX

708	13.5	−15.2292	+ 8.3553	−15.2300	+ 8.3475
715	16.2	13.7010	6.8618	13.6853	6.8562
721	16.8	12.7082	7.4271	12.7260	7.3905
722	16.5	12.6080	5.8831	12.5738	5.8697
725	13.9	11.1092	6.4546	11.0638	6.4422
737	14.0	− 8.1778	+ 7.2274	− 8.1768	+ 7.2227
749	16.8	4.0408	7.4791	4.0170	7.4845
750	15.7	− 3.6342	6.1118	− 3.6470	6.0972
764	13.3	+ 0.7272	8.9626	+ 0.7534	8.9677
805	17.9	9.8170	9.7538		

TABLE 14
SECTION VIII. REDUCED COORDINATES

MEASURES REPEATED FROM SECTION IB

NO.	PLATE III		PLATE V		V_X	V_Y
	X	Y	X	Y	V−III	V−III
	″	″	″	″	″	″
114	+ 618.27	+ 276.86	+ 618.49	+ 275.29	+0.22	−1.57
115	626.13	249.32	626.32	249.52	+0.19	+0.20
116	646.14	253.41	646.50	253.82	+0.36	+0.41

MEASURES REPEATED FROM SECTION V

395	552.49	852.46	552.67	852.14	−0.18	−0.32
396	515.43	886.05	515.91	885.54	−0.48	−0.51
397	− 512.72	+ 760.86	− 513.55	+ 759.59	−0.83	−1.27
398	497.81	908.34	499.26	908.38	−1.45	+0.04
400	338.04	773.94	339.03	773.96	−0.09	+0.02
401	338.25	742.41	336.88	742.61	+1.37	+0.20
403	330.04	696.67	331.02	696.91	−0.98	+0.24
404	260.03	749.71	260.04	749.74	−0.01	+0.03
405	− 246.03	+ 799.77	− 246.24	+ 800.51	−0.21	+0.74
406	239.20	756.77	239.43	756.47	−0.23	−0.30
411	+ 25.26	+ 778.45	+ 25.61	+ 778.07	+0.35	+0.52
412	97.01	781.41	97.46	781.73	−0.15	+0.32
413	111.05	726.48	111.37	726.62	+0.32	+0.14

MEASURES REPEATED FROM SECTION IX

708	− 577.01	+ 316.51	− 577.78	+ 316.36	−0.17	−0.15
715	519.03	259.94	519.19	259.86	+0.44	−0.08
721	481.96	281.41	482.79	280.16	−0.83	−1.25
722	478.16	222.87	477.03	222.50	+1.13	−0.37
725	421.29	244.59	419.74	244.26	+1.55	−0.33
737	− 310.06	+ 274.01	− 310.20	+ 273.97	−0.14	−0.04
749	153.09	283.71	152.39	284.06	+0.70	+0.35
750	137.67	231.88	138.36	231.46	−0.69	−0.42
765	+ 27.83	340.14	+ 28.60	340.48	+0.77	+0.34
805	+ 372.72	370.48				

TABLE 14

SECTION IX. MEASURED COORDINATES

NO.	MAG.	PLATE III		PLATE V	
		x	y	x	y
		r	r	r	r
692	15.7	−18.9448	+ 4.4072	−18.9256	+ 4.3922
693	16.6	18.6602	+ 2.8388	18.6652	+ 2.8116
694	16.2	18.6125	+ 8.1055	18.5926	+ 8.1042
695	15.7	18.0250	+ 9.3622		
696	17.1	17.7478	+ 1.0198	17.7234	+ 0.9856
697	17.4	−17.4148	− 5.9608	−17.4146	− 5.9658
698	17.9	17.3910	− 1.5290		
699	15.7	16.8722	− 1.2180	16.8562	− 1.2188
700	14.4	16.6522	+ 2.5052	16.6309	+ 2.5032
701	14.7	16.5112	− 3.9300	16.4919	− 3.9324
702	16.2	−16.2645	+ 1.3590	−16.2519	+ 1.3594
703	19.0	15.9805	+ 3.4138	15.9482	+ 3.3929
704	19.0	15.7237	+ 1.0815	15.7194	+ 1.0032
705	13.7	15.7372	+ 3.9382	15.7224	+ 3.9396
706	16.8	15.4418	+ 1.1005	15.4306	+ 1.1439
707	14.5	−15.3402	+ 5.4770	−15.3259	+ 5.4954
708	13.5	15.2435	+ 8.3761	15.2304	+ 8.3049
709	16.6	14.9118	+ 0.9972	14.9022	+ 0.9836
710	14.3	14.6893	+ 0.9128	14.6749	+ 0.9132
711	19.0	14.6610	− 4.2920	14.5976	− 4.2871
712	17.3	−14.1505	− 3.8477	−14.1054	− 3.8471
713	16.8	13.9805	+ 0.5265	13.9814	+ 0.4079
714	15.7	13.8290	− 2.4707	13.8106	− 2.4816
715	16.2	13.7170	+ 6.8782	13.6914	+ 6.8706
716	15.1	13.6515	+ 3.0868	14.6349	+ 3.0764
717	17.9	−13.5037	+ 5.3150	−13.4779	+ 5.3114
718	14.7	13.0610	+ 3.5920	13.0494	+ 3.5854
719	19.0	13.0097	− 5.3108		
720	16.4	13.0062	+ 2.7258	12.9816	+ 2.7156
721	16.8	12.7312	+ 7.4428	12.7284	+ 7.4146
722	16.5	−12.6252	+ 5.8982	−12.5982	+ 5.8809
723	13.5	12.1882	+ 1.2082	12.1779	+ 1.2499
724	17.9	11.5705	− 3.0112	11.5676	− 3.0388
725	13.9	11.1315	+ 6.4715	11.0756	+ 6.4684
726	17.9	10.4340	− 5.6412	10.4702	− 5.6613
727	17.9	−10.3555	+ 0.4022	−10.3354	+ 0.3739
728	16.8	10.2255	+ 1.5510	10.2032	+ 1.5389
729	15.1	9.6480	+ 2.5475	9.6422	+ 2.5412
730	15.0	9.5385	− 3.7010	9.5284	− 3.7191
731	17.9	9.4888	− 6.1385	9.4629	− 6.1298

TABLE 14
SECTION IX REDUCED COORDINATES

NO.	PLATE III		PLATE V		V_X	V_Y
	X	Y	X	Y	V−III	V−III
	′	′	′	″	″	″
692	− 717.95	+ 106.06	− 717.90	+ 105.82	−0.05	−0.24
693	707.15	106.61	708.03	105.92	−0.88	−0.69
694	705.37	306.31	705.25	306.55	+0.12	+0.24
695	683.10	353.99				
696	672.54	37.69	672.32	36.74	+0.22	−0.95
697	− 659.86	− 226.97	− 660.63	− 226.75	−0.77	+0.22
698	658.99	− 58.93				
699	639.31	− 47.10	639.43	− 46.78	−0.12	+0.32
700	630.99	+ 94.08	630.87	+ 94.33	+0.12	+0.25
701	625.61	− 149.91	625.63	− 149.63	−0.02	+0.28
702	− 616.28	+ 50.64	− 616.50	+ 50.99	−0.22	+0.35
703	605.86	128.57	604.98	128.09	+0.88	−0.48
704	595.77	40.15	596.31	39.79	−0.54	−0.36
705	596.30	148.47	596.41	148.82	−0.11	+0.35
706	585.08	43.16	585.58	42.86	−0.50	−0.30
707	− 581.25	+ 206.83	− 581.36	+ 206.68	−0.11	−0.15
708	577.60	+ 316.76	577.73	+ 316.60	−0.13	−0.16
709	564.98	+ 37.00	565.31	+ 36.81	−0.33	−0.19
710	556.54	+ 33.82	556.69	+ 34.15	−0.15	+0.33
711	555.43	− 163.53	553.78	− 162.98	+1.65	+0.55
712	− 536.07	− 146.65	− 535.11	− 146.27	+0.96	+0.38
713	529.65	+ 19.21	530.39	+ 18.44	−0.74	−0.77
714	523.89	− 94.42	524.15	− 94.49	−0.26	−0.07
715	519.70	+ 260.06	519.36	+ 260.04	+0.34	−0.02
716	517.19	+ 116.31	517.26	+ 116.21	−0.07	−0.10
717	− 511.60	+ 200.80	− 511.27	+ 200.94	+0.33	+0.14
718	494.80	+ 135.50	495.03	135.53	−0.23	+0.03
719	492.80	− 202.06				
720	492.71	+ 102.66	492.46	102.56	+0.25	−0.10
721	482.31	+ 281.52	482.83	280.71	−0.52	−0.81
722	− 478.28	+ 222.96	− 477.90	+ 222.57	+0.38	−0.39
723	461.68	+ 47.44	461.98	+ 47.04	−0.30	−0.40
724	438.23	− 114.79	438.85	− 115.50	−0.62	−0.71
725	421.64	+ 244.79	420.15	+ 244.92	+1.49	+0.13
726	395.11	− 214.44	397.24	− 214.86	−2.13	−0.42
727	− 392.17	+ 14.71	− 392.10	+ 13.93	+0.07	−0.78
728	387.25	+ 58.27	387.08	+ 58.10	+0.17	−0.17
729	365.35	+ 96.09	365.80	+ 96.12	−0.45	+0.03
730	361.16	− 140.82	361.51	− 141 19	−0.35	−0.37
731	359.26	− 233.24	359.03	− 232.57	+0.23	+0.67

TABLE 14

SECTION IX. MEASURED COORDINATES — CONTINUED

NO.	MAG.	PLATE III		PLATE V	
		x	y	x	y
		r	r	r	r
732	16.8	− 9.3595	− 5.3928	− 9.3612	− 5.4446
733	13.5	9.3140	+ 2.8992	9.2794	+ 2.8896
734	17.9	8.6422	+ 1.5195	8.6069	+ 1.4894
735	17 9	8.6272	− 5.5580	8.6209	− 5.5993
23	12.8	8.5522	+ 5.8622	8.5476	+ 5.8614
736	17.3	− 8.3855	− 3.0016	− 8.3842	− 2.9923
737	14.0	8.2035	+ 7.2420	8.1809	+ 7.2434
738	14.3	8.1450	+ 5.0905	8.1244	+ 5.0949
739	17.9	8.0752	− 2.5510	8.0492	− 2.5491
740	17.3	7.1325	− 3.5205	7.1199	− 3.5176
741	16.8	− 6.6480	+ 1.5318	− 6.5999	+ 1.4989
652	16.8	6.4952	+ 8.9107	6.5159	+ 8.8979
742	14.5	6.4850	+ 4.9670	6.4679	+ 4.9692
743	16.8	6.0808	+ 0.5228	6.0649	+ 0.5271
744	17.9	5.8840	+ 5.3925	5.8872	+ 5.3676
745	10.6	− 5.6652	− 2.0375	− 5.6409	− 2.9598
746	13.2	5.4442	− 6.0407	5.4182	− 6.6531
747	14.7	4.9488	− 2.6890	4.9246	− 2.7101
748	15.3	4.7298	+ 4.9732	4.7024	+ 4.9604
749	16.8	4.0595	+ 7.4882	4.0322	+ 7.5036
750	15.7	− 3.6585	+ 6.1262	− 3.6446	+ 6.1206
751	13.1	3.1916	− 3.7170	3.1729	− 3.7259
752	16.8	3.0782	+ 4.5440	3.0609	+ 4.5274
753	14.7	2.4645	+ 0.4590	2.4386	+ 0.4464
754	14.4	2.0260	+ 7.5292	2.0016	+ 7.5336
755	17.9	− 1.8458	− 1.0642	− 1.8274	− 1.0533
756	14.3	1.8316	− 6.1032	1.8174	− 6.1166
757	11.7	1.4300	− 6.9140	1.3970*	− 6.9245*
758	17.9	1.3622	− 0.6797	1.3724	− 0.6631
759	16.8	1.1622	+ 5.0202	1.1739	+ 5.0162
760	17.9	− 1.0012	− 0.1662	− 0.9722	− 0.2031
761	17.9	− 0.5602	+ 1.7182	− 0.5264	+ 1.7354
762	16.8	+ 0.0228	+ 3.3900	+ 0.0438	+ 3.3774
763	16.8	0.1400	+ 5.4762	0.1634	+ 5.4714
764	18.0	0.5248	+ 0.5220	0.5774	+ 0.5236
765	13.3	+ 0.7220	+ 8.9725	+ 0.7506	+ 8.9672
766	15.7	0.8878	− 6.0220	0.9038	− 6.0451
767	16.8	1.0135	+ 4.0852		
768	16.8	1.0455	+ 6.1325	1.0428	+ 6.1212
769	15.9	1.6465	− 3.0720	1.6688*	− 3.0928*

*Measured and reduced with Section XIII.

TABLE 14

SECTION IX. REDUCED COORDINATES — CONTINUED

NO.	PLATE III		PLATE V		V_Y	V_X
	X	Y	X	Y	V − III	V − III
	″	″	″	″	″	″
732	− 354.36	− 204.96	− 355.17	− 206.59	−0.81	−1.63
733	352.68	+ 109.44	352.04	+ 109.35	+0.64	−0.09
734	327.20	+ 57.17	326.53	+ 56.30	+0.67	−0.87
735	326.58	− 211.18	327.10	− 212.41	−0.52	−1.23
23	323.81	+ 221.84	324.27	+ 222.04	−0.46	+0.20
736	− 317.43	− 114.24	− 318.11	− 113.58	−0.68	+0.66
737	310.59	+ 274.18	310.35	+ 274 45	+0.24	+0.27
738	308.36	+ 192.60	308.22	+ 193.01	+0.14	+0.41
739	305.67	− 97.13	305.40	− 06.76	+0.27	+0.37
740	269.91	− 133.84	270.16	− 133.43	−0.25	+0.41
741	− 251.56	+ 57.75	− 250.41	+ 56.77	+1.15	−0.98
652	245.81	+ 337.54	247.19	+ 337.25	−1.38	−0.29
742	245.40	+ 188.01	245.39	+ 188.32	+0.01	+0.31
743	230.04	− 20.12	230.13	− 20.01	−0.09	+0.11
744	222.61	+ 204.18	223.36	+ 203.46	−0.75	−0.72
745	− 214.26	− 111.65	− 214.40	− 112.21	−0.14	−0.56
746	205.86	− 252.05	205.62	− 252.20	+0.24	−0.15
747	187.09	− 102.18	186.89	− 102.70	+0.20	−0.52
748	178.83	+ 188.35	178.43	+ 188.08	+0.40	−0.27
749	153.43	+ 283.75	153.00	+ 284.52	+0.43	+0.77
750	− 138.21	+ 232.13	− 138.30	+ 232.11	−0.09	−0.02
751	120.44	− 141.06	120.45	− 141.12	−0.01	−0.06
752	116.19	+ 172.17	116.17	+ 171.75	+0.02	−0.42
753	92.89	+ 17.32	92.58	+ 17.08	+0.31	−0.24
754	76.30	+ 285.42	75.98	+ 285.76	+0.32	+0.34
755	− 69.42	− 40.40	− 69.41	− 39.74	+0.01	+0.66
756	68.85	− 231.46	69.05	− 231.68	−0.20	−0.22
757	53.61	− 262.18	53.35	− 262.26	+0.26	−0.08
758	51.08	− 25.79	52.15	− 24.93	−1.07	+0.86
759	43.53	+ 190.34	44.59	+ 190.37	−1.06	+0.03
760	− 37.39	− 6.30	− 36.97	− 7.47	+0.42	−1.17
761	− 20.68	+ 65.18	− 20.05	+ 66.04	+0.63	+0.86
762	+ 1.42	+ 128.60	+ 1.57	+ 128.31	+0.15	−0.29
763	+ 5.86	+ 207.71	+ 6.13	+ 207.70	+0.27	−0.01
764	+ 20.48	+ 19.88	+ 21.81	+ 20.16	+1.33	+0.28
765	+ 27.91	+ 340.31	+ 28.42	+ 340.25	+0.51	−0.06
766	+ 34.29	− 228.22	34.16	− 228.83	−0.13	−0.61
767	38.09	+ 155.01				
768	40.19	+ 232.64	39.49	+ 232.37	−0.70	−0.27
769	63.04	− 116.32	63.19	− 116.88	+0.15	−0.56

TABLE 14

SECTION IX. MEASURED COORDINATES — CONTINUED

NO.	MAG.	PLATE III		PLATE V	
		x	y	x	y
		r	r	r	r
770	15.3	+ 1.6518	− 2.2238	+ 1.6692*	− 2.2435*
771	14.7	1.8080	− 5.3475	1.8176	− 5.3628
772	16.1	1.9892	− 4.3565	2.0156	− 4.3806
773	17.9	2.1630	− 3.1192	2.1848*	− 3.1285*
774	16.8	2.5482	+ 4.6562	2.5846	+ 4.6457
775	15.1	+ 2.8462	− 3.0701	+ 2.8736	− 3.0811
776	17.3	2.9485	− 5.9455	2.9708	− 5.9898
777	14.5	2.9632	− 0.1170		
778	19.0	3.6775	+ 2.9802	3.6984	+ 2.9679
779	19.0	3.7392	+ 4.0690		
780	15.7	+ 4.0135	+ 7.1672	+ 4.0498	+ 7.1574
781	14.7	4.1798	+ 5.3052	4.2011	+ 5.3142
782	19.0	4.4942	− 4.7518	4.4988	− 4.7738
783	16.8	4.5920	+ 0.0500	4.6064	+ 0.0402
784				4.8300	+ 3.1994
785	15.1	+ 5.0388	+ 1.0635	+ 5.0561	+ 1.0532
786	16.8	5.1888	− 6.3395	5.2031	− 6.3664
787	16.8	5.2015	− 5.3625	5.2246	− 5.3611
788	19.0	5.2675	+ 8.0220	5.3306	+ 8.0156
789	11.9	5.9865	+ 3.7820	5.9924	+ 3.7762
790	15.2	+ 6.0508	− 3.5540	+ 6.0628	− 3.5618
791	15.4	6.0850	− 6.3077	6.1066	− 6.3204
792	14.5	6.1172	+ 0.7622	6.1401	+ 0.7404
793		6.6280	+ 8.0348		
794	17.1	6.6750	− 3.5252	6.6581	− 3.5358
795	12.5	+ 7.5175	− 3.0853	+ 7.5278	− 3.1048
796	16.8	8.2098	+ 6.3865	8.2238	+ 6.3994
797	19.0	8.2658	+ 2.6900	8.2333	+ 2.6849
798	17.3	8.4872	− 5.7750	8.5591	− 5.8011
799		8.5603	+ 9.4462		
800	17.3	+ 8.6325	+ 7.2360	+ 8.6264	+ 7.2129
801	15.7	8.7132	− 2.2642	8.7436	− 2.2906
802	16.8	8.7422	− 5.3252	8.7664	− 5.3444
803	15.7	9.0152	− 5.7635	9.0216	− 5.7966
804	15.7	9.6048	− 4.1108	9.6071	− 4.1378
805	17.9	+ 9.8152	+ 9.7560		
806	15.7	10.2592	+ 3.2575	+10.2766	+ 3.2422
807	17.9	10.4358	+ 7.3420		
808	17.3	10.6538	+ 8.0190	10.6421	+ 8.0219
809	16.2	* 10.7570	+ 5.7182	10.7932*	+ 5.7282*

*Measured and reduced with Section XIII.

TABLE 14

SECTION IX. REDUCED COORDINATES — CONTINUED

NO.	PLATE III		PLATE V		I_X	I_Y
	X	Y	X	Y	V − III	V − III
	″	″	″	″	″	″
770	+ 63.24	− 84.16	+ 63.08	− 84.76	−0.16	−0.60
771	69.18	− 202.59	68.83	− 202.92	−0.35	−0.33
772	76.05	− 165.01	76.34	− 165.68	+0.29	−0.67
773	82.03	− 118.08	82.76	− 118.20	+0.13	−0.12
774	97.20	+ 176.75	97.96	+ 176.52	+0.76	−0.23
775	+ 108.54	− 116.18	+ 108.89	− 116.37	−0.35	−0.19
776	112.44	− 225.20	112.56	− 226.63	+0.12	−1.43
777	112.96	− 4.20				
778	140.04	+ 113 27	140.20	+ 112.97	+0.16	−0.30
779	142.37	+ 154.56				
780	+ 152.75	+ 272 05	+ 153.55	+ 271.81	+0.80	−0.24
781	150.07	+ 201.46	150.28	+ 201.04	+0.21	+0.48
782	171.06	− 179.85	170.52	− 180.46	−0.54	−0.61
783	174 74	+ 2.22	174.63	+ 2.04	−0.11	−0.18
784			183.12	+ 121.81		
785	+ 191.08	+ 40.68	+ 191.69	+ 40.46	+0.01	−0.22
786	197.41	− 240.01	197.23	− 240.79	−0.18	−0.78
787	197.89	− 202.96	198.05	− 202.68	+0.16	+0.28
788	200.31	+ 304.53	202.13	+ 304.40	+1.82	−0.13
789	227.00	+ 143.81	227.21	+ 143.73	−0.30	−0.08
790	+ 230.09	− 134.34	+ 229.85	− 134.43	−0.24	−0.09
791	231.40	− 238.75	231.50	− 239.00	+0.10	−0.25
792	232.58	+ 29.32	232.80	+ 28.66	+0.22	−0.66
793	251.91	+ 305.10				
794	253.76	− 133.21	252.43	− 133.42	−1.33	−0.21
795	+ 285.71	− 116.40	+ 285.42	− 117.03	−0.29	−0.54
796	311.91	+ 242.09	311.86	+ 243 28	−0.05	+0.59
797	314.06	+ 102.54	312.20	+ 102.48	−1.86	−0.06
798	322.50	− 218.41	324.52	− 219.19	+2.02	−0.78
799	325.18	+ 358.72				
800	+ 327.94	+ 274.92	+ 327.13	+ 274.14	−0.81	−0.78
801	331.05	− 85.28	331.54	− 86.11	+0.49	−0.83
802	332.17	− 201.34	332.30	− 201.87	+0.22	−0.53
803	342.53	− 217.05	342.07	− 219.00	−0.46	−1.05
804	364.88	− 155.25	364.28	− 156.09	−0.60	−0.84
805	+ 372.78	+ 370.54				
806	389.65	124.17	+ 389.70	+ 123 71	+0.05	−0.46
807	396.33	270.05				
808	404.50	304.73	403.50	304.91	−1.00	+0.18
809	408.52	217.50	409.87	217.44	+1.35	−0.06

TABLE 14

SECTION IX. MEASURED COORDINATES — CONTINUED

NO.	MAG.	PLATE III		PLATE V	
		x	y	x	y
		r	r	r	r
810	14.0	+ 9.1668	+ 1.1546	+ 9.1816	+ 1.1416
811	15.5	9.6302	+ 2.3145	9.6466	+ 2.3139
812	16.2	9.6497	+ 0.2160	9.6534	+ 0.1974
813	17.9	9.8782	− 0.7881	9.8584	− 0.8176
814	16.8	11.2912	+ 0.4185	11.2891	+ 0.4022
815	15.1	+11.7462	− 1.4538	+11.7514	− 1.4606
816	15.7	12.2952	− 0.9418	12.3001	− 0.9641

SECTION X. MEASURED COORDINATES

817	16.8	−29.4435	−12.4171	−29.4376	−12.4553
818	17.9	28.7200	9.3826	28.7196	9.4646
17	10.4	28.5277	19.6694	28.5142	19.7060
819	17.6	28.1560	11.0228	28.1406	11.0753
820	14.7	27.7345	10.9471	27.7074	10.9948
821	18.3	−26.7560	−17.8914	−26.6974	−17.9606
822	16.2	26.4085	13.7914	26.3822	13.8378
823	16.5	26.2102	18.4496	26.1746	18.4913
824	15.7	26.0875	16.9194	26.0419	16.9455
825	13.3	26.0592	19.2641	26.0359	19.2948
826	19.0	−26.0515	−10.8818		
827	16.8	25.3408	12.5081	−25.3134	−12.5383
828	14.4	25.2430	13.4148	25.2177	13.4340
829	17.9	24.2898	18.4476	24.2814	18.5170
830	15.2	23.6582	13.3504	23.6439	13.3835
831	17.9	−23.3985	−15.2946	−23.3326	−15.3178
832	19.0	23.0645	18.3881	23.0759	18.4340
833	14.2	22.8995	13.1426	22.8686	13.1788
834	17.9	22.8837	16.3708		
835	17.9	22.1877	17.5206	22.1594	17.5848
836	17.9	−22.0607	−16.1911	−21.9842	−16.2664
837	15.2	21.8785	13.1198	21.8422	13.1550
838	17.9	21.7902	15.4356	21.7572	15.4830
839	16.6	21.7850	14.6448	21.7242	14.6650
840	14.7	21.4537	19.3051	21.4166	19.3453

TABLE 14

SECTION IX. REDUCED COORDINATES — CONTINUED

NO.	PLATE III		PLATE V		V_X	V_Y
	X	Y	X	Y	V−III	V−III
	″	″	″	″	″	″
810	+ 348.24	+ 44.37	+ 348.16	+ 44.02	−0.08	−0.35
811	365.80	+ 88.38	365.81	+ 88.48	+0.01	+0.10
812	366.56	+ 8.81	366.05	+ 8.25	−0.51	−0.56
813	375.23	− 29.25	373.83	− 30.21	−1.40	−0.96
814	428.81	+ 16.59	428.10	+ 16.10	−0.71	−0.49
815	+ 446.08	− 54.38	+ 445.62	− 54.49	−0.46	−0.11
816	466.90	34.93	466.44	35.64	−0.46	−0.71

SECTION X. REDUCED COORDINATES

817	−1116.13	− 472.90	−1116.72	− 472.95	−0.59	−0.05
818	1088.75	357.80	1089.45	359.51	−0.70	−1.71
17	1081.24	747.80	1081.78	747.88	−0.54	−0.08
819	1067.32	419.93	1067.51	420.57	−0.19	−0.62
820	1051.33	417.05	1051.08	417.50	+0.25	−0.45
821	−1014.07	− 680.27	−1012.85	− 681.61	+1.22	−1.34
822	1000.97	524.80	1000.85	525.25	+0.12	−0.45
823	993.35	701.39	993.03	701.71	+0.32	−0.32
824	988.73	643.37	987.98	643.09	+0.75	+0.28
825	987.61	732.26	987.78	732.18	−0.17	+0.08
826	− 987.49	− 414.46				
827	960.49	476.07	− 960.30	− 475.93	+0.19	+0.14
828	956.76	510.44	956.68	509.89	+0.08	+0.55
829	920.50	701.18	921.22	702.61	−0.72	−1.43
830	896.64	507.88	896.99	507.91	−0.35	−0.03
831	− 886.75	− 581.58	− 885.20	− 581.25	+1.55	+0.33
832	874.02	698.84	875.50	699.41	−1.48	−0.57
833	867.80	490.97	867.58	500.12	+0.28	−0.15
834	867.20	622.35				
835	840.77	665.89	840.73	667.17	+0.04	−1.28
836	− 835.98	− 615.48	− 834.07	− 617.17	+1.91	−1.69
837	829.13	499.02	828.65	499.17	+0.48	−0.15
838	825.74	586.81	825.45	587.45	+0.29	−0.64
839	825.55	556.83	824.19	556.43	+1.36	+0.40
840	812.89	733.50	812.57	733.90	+0.32	−0.40

TABLE 14

SECTION X. MEASURED COORDINATES — CONTINUED

NO.	MAG.	PLATE III		PLATE V	
		x	y	x	y
		r	r	r	r
841	13.2	−21.3425	−14.0676	−21.3194	−14.1026
842	16.0	20.9650	9.2021	20.9299	9.2438
843	13.1	20.9185	18.7861	20.8746	18.8206
844	14.7	20.4412	9.0791	20.4169	9.1206
845	16.6	20.1060	17.3561	20.0882	17.4118
846	17.1	−20.0345	−13.5878	−20.0135	−13.6428
847	16.8	19.1812	17.5454	19.1524	17.6003
848	17.1	18.9732	18.7028	18.9942	18.7470
849	14.7	18.7727	16.7636	18.7404	16.8013
850	14.2	18.0665	14.2756	18.0492	14.3006
851	16.6	−18.0597	−13.4061	−18.0304	−13.4480
852	10.9	17.0935	10.9863	17.0649	11.0246
853	16.8	17.0985	8.1826	17.0674	8.2103
854	10.8	16.6207	14.0354	16.5864	14.0843
855	15.0	15.9337	17.1141	15.9176	17.1638
856	13.9	−14.8105	−17.6014	−14.7786	−17.6270
857	17.3	14.3235	14.0498	14.3012	14.9711
21	11.2	14.1485	8.0226	14.1307	8.0426
858	16.8	14.0545	10.6418	14.0236	10.6708
859	17.3	13.8595	18.8938	13.8176	18.9476
860	17.9	−13.7400	− 9.4278	−13.6566	− 9.4883
861	14.5	13.1035	7.6313	13.0759	7.6630
862	16.2	13.0200	19.1038	12.9820	19.1323
863	17.9	12.8118	9.7306	12.7852	9.7596
864	16.2	12.7952	16.6753	12.7404	16.7176
865	17.3	−11.6720	−13.8814	−11.6584	−13.9228
866	16.2	11.6550	13.7088	11.6309	13.7608
867	17.3	11.2365	10.2948	11.2284	19.3580
868	15.0	10.9575	13.1668	10.9129	13.1810
869	16.2	9.9772	19.0306	9.9449	19.0540
870	15.1	− 9.5047	− 9.9821	− 9.4866	− 9.9986
871	15.4	9.4855	8.5664	9.4529	8.5818
872	17.1	8.3920	16.3946	8.3532	16.4343
873	19.0	8.3445	13.9468	8.2782	14.0056
874	19.0	8.2638	9.1201	8.2196	9.1300
875	17.3	− 8.2480	−17.9328	− 8.2049	−17.9328
876	16.2	7.6062	14.8246	7.5776	14.8450
877	16.6	7.3057	17.3861	7.2776	17.4088
878	17.9	7.1820	11.1536	7.1429	11.1903
879	15.2	7.0555	17.7001	7.0239	17.7223

TABLE 14

SECTION X. REDUCED COORDINATES — CONTINUED

NO.	PLATE III		PLATE V		V_X	V_Y
	X	Y	X	Y	V − III	V − III
	″	″	″	″	″	″
841	− 808.78	− 534.92	− 808.83	− 535.08	−0.05	−0.16
842	794.56	350.42	794.00	350.81	+0.56	−0.39
843	792.60	713.78	792.01	713.98	+0.59	−0.20
844	774.09	345.72	774.54	346.12	+0.15	−0.40
845	761.80	659.51	762.17	660.52	−0.37	−1.01
846	− 759.17	− 516.63	− 759.29	− 517.59	−0.12	−0.96
847	726.72	666.62	726.68	667.63	+0.04	−1.01
848	718.80	710.49	720.69	711.11	−1.89	−0.62
849	711.24	636.95	711.04	637.31	+0.20	−0.36
850	684.50	542.57	684.80	542.45	−0.30	+0.12
851	− 684.26	− 509.61	− 684.07	− 510.12	+0.19	−0.51
852	681.80	417.86	681.56	418.22	+0.24	−0.36
853	647.90	311.50	647.49	311.80	+0.41	−0.30
854	629.65	533.37	629.31	534.19	+0.34	−0.82
855	603.53	650.04	603.98	650.94	−0.45	−0.90
856	− 560.91	− 668.44	− 560.79	− 668.46	+0.12	−0.02
857	542.49	567.87	542.65	567.72	−0.16	+0.15
21	535.99	305.22	536.10	304.97	−0.11	+0.25
858	532.37	404.52	532.07	404.98	+0.30	−0.46
859	524.46	717.37	524.35	718.50	+0.11	−1.13
860	− 520.47	− 358.47	− 518.14	− 359.78	+2.33	−1.31
861	496.36	290.32	496.09	290.53	+0.27	−0.21
862	492.95	725.28	492.69	725.47	+0.26	−0.19
863	485.25	370.12	485.09	370.03	+0.16	+0.09
864	484.48	633.19	483.81	633.89	+0.67	−0.70
865	− 441.92	− 527.18	− 442.40	− 527.86	−0.48	−0.68
866	441.28	520.64	441.36	521.71	−0.08	−1.07
867	425.29	732.39	426.15	733.95	−0.86	−1.56
868	414.83	500.04	414.12	499.70	+0.71	+0.34
869	377.52	722.29	377.47	722.37	+0.05	−0.08
870	− 359.78	− 379.19	− 359.98	− 378.95	−0.20	+0.24
871	359.09	325.52	358.69	325.23	+0.40	+0.29
872	317.44	622.24	317.07	622.96	+0.37	−0.72
873	315.69	529.43	314.20	530.86	+1.49	−1.43
874	312.73	346.42	311.92	346.30	+0.81	+0.12
875	+ 311.95	− 680.55	− 311.46	− 679.78	+0.49	+0.77
876	287.66	562.66	287.63	562.66	+0.03	0.00
877	276.21	659.75	276.28	659.87	−0.07	−0.12
878	271.65	423.45	271.10	424.05	+0.55	−0.60
879	266.71	671.64	266.66	671.75	+0.05	−0.11

TABLE 14

SECTION X. MEASURED COORDINATES — CONTINUED

NO.	MAG.	PLATE III		PLATE V	
		x	y	x	y
		r	r	r	r
880	16.6	− 6.9958	−17.1011	− 6.9559	−17.1413
881	17.9	6.9837	10.9896	6.9819	11.0243
882	15.2	6.8705	15.7618	6.8469	15.7933
883	17.9	6.5418	12.5163	6.5874	12.5538
884	19.0	6.1920	10.2438		
885	19.0	− 6.1675	− 7.5841		
886	17.9	5.8425	11.3776	− 5.8086	−11.4008
887	19.0	5.7070	13.0000	5.7214	12.9936
888	19.0	5.3610	12.7648	5.3329	12.7848
889	13.3	4.9002	7.3733		
890	13.4	− 4.6805	−17.2481	− 4.6549	−17.2526
891	16.8	4.4720	14.1158	4.4512	14.1303
892	16.8	4.2465	13.7996	4.2219	13.8246
893	13.4	4.1947	17.0026	4.1496	17.0170
894	15.2	3.8900	9.0616	3.8682	9.0870
895	19.0	− 3.8782	− 6.9206		
896	13.4	3.3722	10.7871	− 3.3449	−10.8073
897	19.0	3.3552	7.0471		
898	14.4	2.8708	15.8421	2.8436	15.8518
899	14.1	2.4442	15.2206	2.4062	15.2440
900	17.9	− 2.3648	− 9.3914	− 2.3964	− 9.4136
901	15.5	2.1962	14.0231	2.1684	14.0382
902	15.2	1.5292	7.5772	1.5116	7.5860
757	11.7	1.4468	6.9186	1.3918*	6.9208*
903	17.9	1.4318	15.5071	1.3716	15.5676
904	16.8	− 1.0075	−16.7098	− 0.9712	−16.7408
905	16.2	− 0.6175	9.8886	− 0.6096	9.9128
906	14.5	− 0.4590	19.4706	− 0.4126	19.5043
907	16.2	− 0.0777	10.7338	− 0.0552	10.7588
908	15.5	+ 0.0992	11.2408	+ 0.1236	11.2553
909	15.5	+ 0.6900	−10.5898	+ 0.7023	−10.6018
910	17.9	0.6905	15.3638	0.7451	15.4053
911	16.8	0.9880	7.7634	0.9960	7.7836
912	14.7	1.2152	8.6036	1.2381	8.6198
913	17.7	1.4325	9.4684	1.4523	9.4953
914	17.3	+ 1.8672	−14.1494	+ 1.8893	−14.1550
915	16.1	2.1108	11.8518	2.1363	11.8620
916	14.3	2.3410	9.2796	2.3681	9.2856
917	15.5	4.3902	11.4568	4.4053	11.4753
918	15.5	4.6052	11.3226	4.6368	11.3380

*Measured and reduced with Section XIII.

TABLE 14

SECTION X REDUCED COORDINATES — CONTINUED

No.	PLATE III		PLATE V		V_X	V_Y
	X	Y	X	Y	V—III	V—III
	″	″	″	″	″	″
880	− 264.40	− 648.93	− 264.08	− 649.71	+0.38	−0.78
881	264.13	417.22	265.00	417.75	−0.87	−0.53
882	259.73	598.14	259.93	598.59	−0.20	−0.45
883	247.33	475.07	250.05	475.73	−2.72	−0.66
884	234.11	388.88				
885	− 253.23	− 288.04				
886	220.83	431.85	− 220.50	− 431.97	+0.33	−0.12
887	215.05	493.35	217.21	492.37	−1.56	+0.98
888	202.53	484.41	202.47	484.44	+0.06	−0.03
889	185.16	279.96				
890	− 176.62	− 654.34	− 176.81	− 653.84	−0.19	+0.50
891	168.78	535.57	169.05	535.42	−0.27	+0.15
892	160.23	523.56	160.34	523.82	−0.11	−0.26
893	158.20	645.00	157.64	644.88	+0.56	+0.12
894	146.80	343.90	146.88	344.15	−0.08	−0.25
895	− 146.40	− 262.73				
896	127.13	409.29	− 127.05	− 409.36	+0.08	−0.07
897	126.56	267.49				
898	108.00	600.91	108.09	600.64	−0.09	+0.27
899	91.83	577.65	91.49	577.57	+0.34	+0.08
900	− 88.94	− 356.30	− 91.06	− 356.47	−2.12	−0.17
901	82.43	554.64	82.47	554.59	−0.04	+0.05
902	57.28	287.46	57.48	287.13	−0.20	+0.33
757	54.16	262.48	53.15	262.12	+1.01	+0.36
903	53.42	588.10	52.26	589.80	+1.16	−1.70
904	− 37.30	− 633.67	− 37.08	− 634.27	+0.22	−0.60
905	22.04	375.03	23.29	375.33	−0.05	−0.30
906	10.43	738.31	15.03	739.05	+0.50	−0.74
907	− 2.15	407.04	− 2.27	407.39	−0.12	−0.35
908	+ 4.57	426.25	+ 4.50	426.21	−0.07	+0.04
909	+ 26.97	− 401.52	+ 26.46	− 401.40	−0.51	+0.12
910	27.09	582.52	28.03	583.56	+0.94	−1.04
911	38.22	294.34	37.65	294.52	−0.57	−0.18
912	46.86	326.18	46.80	326.22	−0.06	−0.04
913	55.12	358.05	54.92	359.41	−0.20	−0.46
914	+ 71.71	− 536.40	+ 71.44	− 536.10	−0.27	+0.30
915	80.90	449.27	80.83	449.13	−0.07	+0.14
916	89.58	351.73	89.65	351.42	+0.07	+0.31
917	167.36	434.14	166.90	434.37	−0.46	−0.23
918	175.52	429.03	175.68	429.15	+0.16	−0.12

TABLE 14

SECTION X. MEASURED COORDINATES — CONTINUED

NO.	MAG.	PLATE III		PLATE V	
		x	y	x	y
		r	r	r	r
919	17.3	+ 5.0082	− 9.7846	+ 5.0471	− 9.8133
920	15.2	5.7742	10.2418	5.8038	10.2523
921	14.7	6.0875	11.4731	6.1076	11.4736
922	17.9	6.1535	9.6486	6.1786	9.7060
923	16.2	6.7838	13.0521	6.8108	13.0536
924	16.1	+ 7.2865	− 9.2481	+ 7.3266	− 9.2558
925	17.9	7.3135	12.5776	7.3413	12.6216
926	16.5	7.3880	18.7391	7.4336	18.7555
927	14.4	7.5390	17.3043	7.5796	17.3048
928	14.0	7.7685	11.9731	7.7966	11.9730
929	13.3	+ 8.2492	−17.6453	+ 8.2898	−17.6570
930	14.2	8.3977	9.1768	8.4176	9.1845
931	16.2	8.4148	11.0740	8.4381	11.1085
932	16.8	8.5088	12.0973	8.5138	12.1050
933	13.3	8.9050	11.1371	8.9248	11.1416
934	10.8	+ 8.9548	−13.7334	+ 8.9811	−13.7326
935	13.1	9.3458	13.0238	9.3808	13.0268
936	15.1	10.1830	11.2711	10.2081	11.2805
937	12.8	10.1918	7.9250	10.2172	7.9243
938	12.8	10.6818	12.4421	10.7206	12.4383
939	13.4	+11.3277	− 7.1441		
940	13.3	11.6035	10.0774	+11.6428	−10.0910
941	16.1	11.9545	15.8496	11.9938	15.8693
942	16.5	11.9692	10.8216	11.9993	10.8390
943	16.4	12.3495	11.6734	12.3741	11.6688
944	17.9	12.6555	11.3944	12.6653	11.4083

SECTION XI. MEASURED COORDINATES

945	15.7	−28.2155	−35.5726	−28.2193	−35.5687
946	10.7	27.9947	21.3729	27.9876	21.3527
947	13.3	27.8662	32.6719	27.8811	32.6620
948	16.8	27.7322	34.5552	27.7276	34.5402
949	13.7	27.7035	36.1874	27.7001	36.1784
950	14.7	−27.5315	−20.4842	−27.5361	−20.4694
951	13.7	27.2760	33.2814	27.2678	33.2707
952	14.7	27.2422	44.1784	27.2313	44.1760
953	17.0	27.0560	33.7246	27.0263	33.7127
954	15.7	26.9395	42.6156	26.9409	42.6154

TABLE 14

SECTION X REDUCED COORDINATES Continued

No.	Plate III		Plate V		V_X	V_Y
	X	Y	X	Y		
	"	"	"	"	"	"
919	+ 190.77	− 370.69	+ 191.26	− 371.32	+0.49	−0.63
920	210.84	387.97	219.95	387.93	+0.11	+0.04
921	231.75	434.04	231.46	434.23	−0.29	+0.41
922	234.22	365.46	234.18	367.20	−0.04	−1.74
923	258.20	494.45	258.12	494.12	−0.08	+0.33
924	+ 277.19	− 350.19	+ 277.72	− 350.08	+0.53	+0.11
925	278.28	476.43	278.24	477.72	−0.04	−1.29
926	281.24	710.03	281.67	710.32	+0.43	−0.29
927	286.94	655.62	287.23	655.30	+0.29	+0.32
928	295.53	453.48	295.52	453.10	−0.01	+0.38
929	+ 313.89	− 668.50	+ 314.16	− 668.63	+0.27	−0.13
930	319.34	347.41	319.10	347.33	−0.24	+0.08
931	320.03	419.36	319.86	420.29	−0.17	−0.93
932	323.02	458.13	322.72	458.06	−0.90	+0.05
933	338.63	421.70	338.32	421.53	−0.31	+0.17
934	+ 340.57	− 520.13	+ 340.42	− 519.78	−0.15	+0.35
935	355.39	493.20	355.59	493.00	+0.20	+0.20
936	387.11	426.69	386.99	426.74	−0.12	−0.05
937	387.38	299.85	387.37	299.47	−0.01	+0.38
938	406.06	471.05	406.42	470.62	+0.36	+0.43
939	− 430.45	− 270.14				
940	440.98	381.33	+ 441.42	− 381.61	+0.44	−0.28
941	454.41	600.16	454.67	600.68	+0.26	−0.52
942	454.87	409.52	454.93	409.92	+0.06	−0.40
943	469.31	441.79	469.14	441.37	−0.17	+0.42
944	+ 480.91	431.19	+ 480.19	431.48	−0.72	−0.29

SECTION XI. REDUCED COORDINATES

945	−1070.68	−1349.27	−1070.85	−1349.58	−0.17	−0.31
946	1062.16	810.80	1061.95	810.49	+0.21	+0.31
947	1057.39	1239.26	1058.00	1239.34	−0.61	−0.08
948	1052.33	1310.67	1052.18	1310.56	+0.15	+0.11
949	1051.26	1372.57	1051.15	1372.68	+0.11	−0.11
950	−1044.57	− 777.08	−1044.82	− 776.97	−0.25	+0.11
951	1035.01	1262.35	1034.73	1262.40	+0.28	−0.05
952	1033.83	1675.58	1033.43	1675.94	+0.40	−0.36
953	1026.66	1279.15	1025.57	1279.15	+1.09	0.00
954	1022.33	1616.31	1022.40	1616.75	−0.07	−0.44

TABLE 14

SECTION XI. MEASURED COORDINATES — CONTINUED

NO.	MAG.	PLATE III		PLATE V	
		x	y	x	y
		r	r	r	r
955	15.2	−26.8927	−22.4446	−26.8821	−22.4320
956	14.9	26.5120	26.4474	26.5166	26.4397
957	15.5	26.3452	35.0204	26.3333	35.0094
958	16.8	26.2865	43.5506	26.2843	43.5482
959	14.4	25.6605	24.8926	25.6596	24.8864
960	13.1	−25.5730	−22.6822	−25.5616	−22.6532
961	15.0	24.4750	40.1216	24.4593	40.1180
962	17.6	24.4290	37.9264	24.3866	37.9150
963	15.4	24.3537	40.6039	24.3533	40.5914
964	15.7	24.3382	30.0216	24.3368	30.0247
965	16.6	24.3255	−33.3422	−24.3053	−33.3847
966	17.6	24.2432	37.5954	24.2433	37.4747
967	13.5	23.9975	23.8779	23.9781	23.8030
968	13.3	23.8280	41.1529	23.8268	41.1440
969	16.6	23.6237	33.5004	23.6133	33.4960
970	13.1	−23.3882	−42.7716	−23.3743	−42.7602
971	13.4	22.7780	44.8936	22.7568	44.8764
972	16.0	22.7368	22.6472	22.7366	22.6160
973	16.8	22.6800	25.5669	22.6848	25.5744
974	15.3	22.2410	24.7516	22.2291	24.7384
975	14.3	−22.1038	−35.6209	−22.1039	−35.6032
976	15.2	21.9780	20.7304	21.9886	20.7312
977	16.2	21.9475	20.2202	21.9283	20.2202
978	15.9	21.6652	31.2574	21.6551	31.2434
979	15.9	21.6195	43.1784	21.6109	43.1714
980	13.3	−21.5425	−28.7552	−21.5279	−28.7362
981	15.1	21.4935	20.9472	21.4873	20.9300
982	14.0	21.4135	30.2686	21.3956	30.2532
983	15.4	21.3070	42.2749	21.3201	42.2574
984	15.2	21.0425	26.7046	21.0351	26.6928
985	15.2	−21.0020	−41.8526	−21.0053	−41.8517
986	14.4	20.9040	21.4039	20.8956	21.3077
987	17.3	20.1688	27.5504	20.1703	27.5377
988	14.9	19.9967	35.9612	19.9983	35.9374
989	16.8	19.9278	27.4614	19.9251	27.4517
990	14.1	−19.8715	−23.1006	−19.8641	−23.0942
991	14.4	19.6218	44.7046	19.6126	44.7004
992	15.5	19.1035	32.8582	19.0911	32.8464
993	16.5	19.0972	36.8652	19.0843	36.8302
994	15.0	18.4528	21.3304	18.4551	21.3472

TABLE 14

SECTION XI. REDUCED COORDINATES Continued

No.	Plate III		Plate V		V_X V−III	V_Y V−III
	X	Y	X	Y		
	″	″	″	″	″	″
955	−1020.35	− 851.40	−1020.02	− 851.37	+0.33	+0.03
956	1005.95	1003.18	1006.18	1003.33	−0.23	−0.15
957	999.71	1328.27	999.29	1328.30	+0.42	−0.03
958	997.56	1651.74	997.50	1652.10	+0.06	−0.36
959	973.63	944.19	973.66	944.40	−0.03	−0.21
960	− 970.28	− 860.37	− 969.92	− 859.71	+0.36	+0.66
961	928.80	1521.65	928.24	1521.05	+0.56	−0.30
962	927.03	1438.40	925.46	1438.41	+1.57	−0.01
963	924.20	1539.93	924.22	1539.90	−0.02	+0.03
964	923.50	1138.64	923.51	1139.20	−0.01	−0.56
965	− 923.06	−1264.56	− 922.34	−1266.61	+0.72	−2.05
966	919.97	1422.43	920.02	1421.71	−0.05	+0.72
967	910.52	905.66	909.86	905.53	+0.66	+0.13
968	904.26	1560.74	904.25	1560.83	+0.01	−0.09
969	896.43	1270.54	896.09	1270.81	+0.34	−0.27
970	− 887.59	−1622.10	− 887.09	−1622.11	+0.50	−0.01
971	864.45	1702.55	863.68	1702.33	+0.77	+0.22
972	862.67	858.04	862.75	858.19	−0.08	+0.75
973	860.54	969.66	860.81	970.38	−0.27	−0.72
974	843.88	938.73	843.51	938.66	+0.37	+0.07
975	− 838.78	−1350.90	− 838.84	−1350.66	−0.06	+0.24
976	833.86	786.46	834.36	786.69	−0.50	−0.23
977	832.70	706.88	832.07	767.31	+0.63	−0.43
978	822.10	1185.42	821.78	1185.31	+0.32	+0.11
979	820.48	1637.47	820.20	1637.63	+0.28	−0.16
980	− 817.41	−1090.53	− 816.94	−1090.23	+0.47	+0.30
981	815.48	794.44	815.34	794.55	+0.14	−0.11
982	812.54	1147.91	811.93	1147.75	+0.61	+0.16
983	808.61	1603.20	809.16	1602.96	−0.55	+0.24
984	798.42	1012.75	798.23	1012.72	+0.19	+0.03
985	− 797.04	−1587.18	− 797.21	−1587.56	−0.17	−0.38
986	793.11	811.74	792.90	811.92	+0.21	−0.18
987	765.28	1044.79	765.43	1044.73	−0.15	+0.06
988	758.83	1363.73	758.96	1363.25	−0.13	+0.48
989	756.14	1041.41	756.12	1041.46	+0.02	−0.05
990	− 753.96	− 876.04	− 753.78	− 876.22	+0.18	−0.18
991	744.70	1695.28	744.40	1695.54	+0.30	−0.26
992	724.91	1246.04	724.52	1246.00	+0.39	+0.04
993	724.71	1397.99	724.29	1397.41	+0.42	+0.58
994	700.11	809.21	700.31	809.92	−0.20	−0.71

TABLE 14

SECTION XI. MEASURED COORDINATES — CONTINUED

NO.	MAG.	PLATE III		PLATE V	
		x	y	x	y
		r	r	r	r
995	17.9	−18.2115	−22.2199	−18.1818	−22.2302
996	15.7	18.1978	30.3372	18.2566	30.2974
997	15.5	18.1970	32.7632	18.1980	32.7647
998	16.8	18.1680	30.6402	18.1728	30.6410
999	14.2	18.0662	36.3152	18.0676	36.3104
1000	17.1	−17.9323	−26.2462	−17.9413	−26.2504
1001	14.3	17.9000	40.5759	17.8933	40.5680
1002	15.1	17.8958	35.9499	17.8908	35.9344
1003	15.1	17.2365	35.4436	17.2321	35.4417
1004	15.7	16.7835	37.3259	16.7079	37.3282
1005	17.1	−16.7318	−25.1574	−16.7216	−25.1470
1006	15.5	16.6892	48.1829	16.6803	48.1887
1007	16.8	16.0572	47.0452	16.0549	47.0460
1008	16.5	15.5305	29.8146	15.5231	29.8060
1009	17.9			15.4749	46.2910
1010	14.7	−15.4250	−30.4989	−15.4219	−30.4834
1011	16.4	15.3500	27.8146	15.3503	27.7890
1012	14.7	14.7502	23.4874	14.7441	23.4737
1013	15.2	14.6618	39.1572	14.6701	39.1430
1014	16.8	14.4468	43.5279	14.4491	43.5197
1015	15.5	−14.1742	−26.2419	−14.1831	−26.2292
1016	13.5	14.0612	38.8389	14.0646	38.8274
1017	15.2	13.8688	39.0382	13.8756	39.0342
1018	15.0	13.8565	35.8807	13.8541	35.8687
1019	16.8	13.5398	20.1449	13.5216	20.1552
1020	16.8	−13.3110	−28.7009	−13.3346	−28.7007
1021	16.3	12.7430	34.5924	12.7356	34.5897
1022	16.8	12.5768	45.7246	12.5609	45.6870
1023	13.4	12.5298	41.0526	12.5103	41.0414
1024	15.1	12.2000	20.4802	12.1873	20.4802
1025	17.3	−11.7790	−32.4954	−11.7373	−32.4894
1026	16.2	11.6782	21.3284	11.6781	21.3230
1027	13.7	11.3900	22.8596	11.3576	22.8550
1028	14.7	11.2070	20.6164	11.2039	20.6170
1029	14.2	11.2372	24.6474	11.2318	24.6342
1030	15.2	−11.2345	−36.4166	−11.2476	−36.3950
1031	14.4	11.0645	25.4124	11.0603	25.4087
1032	14.1	10.4515	43.0856	10.4481	43.0816
1033	16.2	10.3590	31.3762	10.3546	31.3732
1034	14.7	10.3202	32.3742	10.3091	32.3697

TABLE 14

SECTION XI. REDUCED COORDINATES—CONTINUED

NO.	PLATE III		PLATE V		V_X	V_Y
	X	Y	X	Y	V−III	V−III
	″	″	″	″	″	″
995	− 690.96	− 842.59	− 689.95	− 843.39	+1.01	−0.80
996	690.52	1150.41	692.84	1149.31	−2.32	+1.10
997	690.52	1242.40	690.67	1242.87	−0.15	−0.47
998	689.39	1162.12	689.67	1162.34	−0.28	−0.22
999	685.59	1377.09	685.72	1377.32	−0.13	−0.23
1000	− 680.41	− 995.26	− 680.85	− 995.83	−0.44	−0.57
1001	679.32	1538.66	679.14	1538.77	+0.18	−0.11
1002	679.12	1363.24	679.01	1363.06	+0.11	+0.18
1003	654.10	1344.02	654.02	1344.35	+0.08	−0.33
1004	636.93	1415.38	636.42	1415.87	+0.51	−0.49
1005	− 634.85	− 953.94	− 634.57	− 953.94	+0.28	0.00
1006	633.46	1827.08	633.18	1827.71	+0.28	−0.63
1007	609.47	1783.92	609.44	1784.35	+0.03	−0.43
1008	589.31	1130.50	589.14	1130.57	+0.17	−0.07
1009			587.43	1755.70		
1010	− 585.32	−1156.45	− 585.30	−1156.26	+0.02	+0.19
1011	582.44	1054.65	582.57	1054.08	−0.13	+0.57
1012	559.64	890.54	559.54	890.42	+0.10	+0.12
1013	556.44	1484.75	556.85	1484.61	−0.41	+0.14
1014	548.33	1650.49	548.49	1650.57	−0.16	−0.08
1015	537.81	− 994.98	− 538.27	− 994.88	−0.46	+0.10
1016	533.65	1472.60	533.87	1472.62	−0.22	+0.04
1017	526.35	1480.22	526.70	1480.45	−0.35	−0.23
1018	525.86	1360.48	525.86	1360.41	0.00	+0.07
1019	513.68	763.75	513.13	764.53	+0.55	−0.78
1020	− 505.09	−1088.20	− 506.10	−1088.57	−1.01	−0.37
1021	483.59	1311.59	483.42	1311.87	+0.17	−0.28
1022	477.40	1733.73	476.88	1732.68	+0.52	+1.05
1023	475.57	1556.56	475.26	1556.52	+0.31	+0.04
1024	462.85	776.42	462.51	776.80	+0.34	−0.38
1025	− 447.00	−1232.04	− 445.53	−1232.19	+1.47	−0.15
1026	443.06	808.57	443.20	808.74	−0.14	−0.17
1027	432.14	866.62	431.05	866.83	+1.09	−0.21
1028	428.59	781.56	428.62	781.96	−0.03	−0.40
1029	426.30	934.41	426.30	934.29	+0.06	+0.12
1030	− 426.37	−1380.71	− 426.98	−1380.27	−0.61	+0.44
1031	419.81	963.42	419.80	963.65	+0.01	−0.23
1032	396.73	1633.58	396.70	1633.80	+0.03	−0.22
1033	393.11	1189.55	393.07	1189.81	+0.04	−0.26
1034	391.64	1227.39	391.35	1227.59	+0.29	−0.20

TABLE 14

SECTION XI. MEASURED COORDINATES — CONTINUED

NO.	MAG.	PLATE III		PLATE V	
		x	y	x	y
		r	r	r	r
1035	14.0	−10.0478	−24.8059	−10.0460	−24.7944
1036	13.5	9.8995	40.5726	9.8911	40.5622
1037	16.8	9.8500	28.0474	9.8583	28.0627
1038	16.8	9.7252	32.7819	9.7356	32.8044
1039	15.2	9.6810	41.1506	9.6751	41.1482
1040	15.0	− 9.5900	−22.0309	− 9.5946	−22.0354
1041	15.7	9.5078	33.4424	9.4713	33.4317
1042	13.5	9.3613	39.3142	9.3276	39.3032
1043	17.3	9.1820	38.1539	9.1773	38.1172
1044	17.9	9.1810	43.0012	9.1591	43.0270
1045	14.1	− 9.1022	−35.1936	− 9.0769	−35.1840
1046	14.7	8.5510	30.4339	8.5408	30.4300
1047	16.2	8.3690	38.4006	8.3615	38.3024
1048	17.3	8.2725	40.8644	8.2868	40.8884
1049	16.8	8.2255	40.1654	8.1953	40.1514
1050	16.8	− 7.5912	−26.1789	− 7.5076	−26.1790
1051	14.7	7.5680	38.4594	7.5768	38.4460
1052	15.5	7.4692	20.7542	7.4626	20.7412
1053	14.5	7.4422	36.1499	7.4416	36.1430
1054	14.5	7.4218	20.4244	7.4111	20.4142
1055	16.2	− 7.1760	−39.9266	− 7.1726	−39.9154
1056	17.3	6.9048	28.2289	6.9156	28.2500
1057	14.3	6.7885	32.6642	6.7751	32.6576
1058	16.8	6.7173	42.4279	6.7343	42.4097
1059	17.3	6.6562	27.6889	6.6211	27.7220
1060	14.4	− 6.5225	−23.1189	− 6.5121	−23.1120
1061	16.6	6.3598	35.0582	6.3629	35.0697
1062	13.4	6.3410	34.5552	6.3263	34.5587
1063	16.6	6.3290	35.5142	6.3051	35.5200
1064	16.8	6.1862	27.2596	6.1776	27.2692
1065	15.4	− 5.8402	−33.3284	− 5.8416	−33.3150
1066	15.2	5.5148	22.7089	5.5101	22.7197
1067	15.4	5.4360	31.2149	5.4421	31.2004
1068	14.4	5.4025	24.5934	5.3968	24.5817

TABLE 14

SECTION XI. REDUCED COORDINATES — CONTINUED

NO.	PLATE III		PLATE V		V_Y	V_X
	X	Y	X	Y	V−III	V−III
	″	″	″	″	″	″
1035	− 381.23	− 940.39	− 381.31	− 940.32	−0.08	+0.07
1036	375.76	1538.27	375.55	1538.24	+0.21	+0.03
1037	374.10	1063.30	374.21	1064.25	−0.11	−0.95
1038	369.07	1242.83	369.59	1244.05	−0.52	−1.22
1039	367.48	1560.18	367.36	1560.46	+0.12	−0.28
1040	− 364.06	− 835.48	− 364.16	− 835.68	−0.10	−0.20
1041	360.83	1267.87	359.57	1267.83	+1.26	+0.04
1042	355.33	1490.53	354.16	1490.48	+1.17	+0.05
1043	348.51	1446.53	348.45	1445.50	+0.06	+1.03
1044	348.52	1630.34	347.80	1631.68	+0.72	−1.34
1045	345.46	−1334.27	− 344.62	−1334.27	+0.84	0.00
1046	324.40	1153.76	324.50	1154.20	−0.10	−0.44
1047	317.67	1455.86	317.51	1455.91	+0.16	−0.05
1048	314.03	1549.28	314.69	1550.55	−0.66	−1.27
1049	312.24	1522.77	311.21	1522.60	+1.03	+0.17
1050	− 288.03	− 992.37	− 287.30	− 992.73	+0.73	−0.36
1051	287.28	1458.06	287.74	1457.91	−0.46	+0.15
1052	283.35	786.66	283.27	786.52	+0.08	+0.14
1053	282.48	1370.48	282.59	1370.57	−0.11	−0.09
1054	281.55	774.15	281.31	774.12	+0.24	+0.03
1055	− 272.42	−1513.68	−272.41	−1513.61	+0.01	+0.07
1056	262.01	1070.09	262.58	1071.24	−0.57	−1.15
1057	257.64	1238.27	257.28	1238.38	+0.36	−0.11
1058	255.05	1608.52	255.80	1608.18	−0.75	+0.34
1059	252.57	1049.00	251.40	1051.21	+1.17	−1.61
1060	− 247.45	− 876.30	− 247.23	−876.68	+0.32	−0.38
1061	241.40	1329.04	241.66	1329.83	−0.26	−0.79
1062	240.68	1309.97	240.27	1310.45	+0.41	−0.48
1063	240.24	1346.33	239.47	1346.90	+0.77	−0.57
1064	234.74	1033.61	234.57	1034.02	+0.17	−0.41
1065	− 221.67	−1263.43	− 221.87	−1263.27	−0.20	+0.16
1066	209.22	860.72	209.23	861.47	−0.01	−0.27
1067	206.31	1183.27	206.70	1183.07	−0.39	+0.20
1068	204.97	932.17	204.93	932.08	+0.04	+0.09

TABLE 14
SECTION XII. MEASURED COORDINATES

NO.	MAG.	PLATE III		PLATE V	
		x	y	x	y
		r	r	r	r
1069	11.9	−46.8494	−50.1576		
1070	17.3	46.7698	50.6938	−46.7348	−50.7600
1071	17.0	46.6696	54.6721		
1072	17.9	46.2776	59.0854		
7	10.2	46.2531	56.3848	46.1855	56.4540
1073	17.0	− 46.1586	−52.0011	−46.1101	−52.0428
1074	15.0	45.7348	54.9936	45.6776	55.0715
1075	19.0	45.7001	48.5468		
1076	15.4	45.6884	53.5316	45.6326	53.5852
1077	16.8	44.9826	56.8526	44.9321	56.8990
1078	19.0	−44.6874	−60.1291	−44.5914	−60.2008
1079	17.9	44.3044	57.1014		
1080	19.0	44.2536	56.0223	44.1474	56.0468
1081	13.9	44.1801	58.9798	44.0966	59.0515
1082	15.7	43.8856	57.0596	43.8261	57.1330
1083	13.7	−43.3056	−56.8881	−43.2324	−56.9425
1084	15.7	43.2728	51.9866	43.2228	52.0555
1085	16.8	43.1931	52.7984	43.1278	52.8572
1086	16.8	43.0926	49.4621	43.0341	49.5022
1087	13.4	42.8384	60.7281	42.7611	60.7883
1088	11.9	−42.6886	−59.0748	−42.6411	−59.1375
1089	17.9	42.5716	58.7696	42.5566	58.7950
1090	10.8	41.1028	54.6131	41.0314	54.6745
1091	16.8	40.6716	59.2998	40.5808	59.3348
1092	15.0	40.6058	49.9513	40.5688	49.9982
1093	15.7	−40.4211	−51.6368	−40.3618	−51.6755
1094	15.7	39.7386	50.8818	39.6964	50.9119
1095	17.2	39.5846	59.0894	39.5085	59.1490
1096	17.9	39.2196	51.3146	39.1394	51.3408
1097	16.2	38.7928	51.5994	38.7301	51.6352
1098	14.4	−38.4531	−49.3316	−38.4004	−49.3700
1099	19.0	38.1348	54.3156	38.0868	54.3555
1100	16.2	37.9958	53.3593	37.9141	53.4092
1101	19.0	37.7108	53.9826		
1102	14.2	37.1144	51.6288	37.0494	51.6742
1103	17.9	−37.0578	−58.2423	−36.9841	−58.2798
1104	14.2	36.4054	53.5654	36.3536	53.5960
1105	16.8	36.3184	59.2018	36.2634	59.2623
1106	16.2	36.0956	55.4466	36.0291	55.4888
1107	16.8	36.0796	56.3256	36.0188	56.3345

TABLE 14

SECTION XII. REDUCED COORDINATES

NO.	PLATE III		PLATE V		V_X	V_Y
	X	Y	X	Y	V−III	V−III
	″	″	″	″	″	″
1069	−1775.07	−1905.15				
1070	1772.03	1925.47	−1773.31	−1925.98	−0.68	−0.51
1071	1768.75	2076.30				
1072	1753.79	2243.59				
7	1752.91	2141.20	1752.54	2141.84	+0.37	−0.64
1073	−1749.42	−1974.99	−1749.63	−1974.59	−0.21	+0.40
1074	1733.28	2088.42	1733.26	2089.41	+0.02	−0.99
1075	1732.10	1843.99				
1076	1731.55	2032.99	1731.54	2033.05	+0.01	−0.06
1077	1704.71	2158.84	1705.00	2158.66	−0.29	+0.18
1078	−1693.44	−2283.05	−1692.12	−2283.84	+1.32	−0.79
1079	1678.98	2168.23				
1080	1677.08	2127.31	1675.23	2126.32	+1.85	+0.99
1081	1674.22	2239.43	1673.34	2240.24	+0.88	−0.81
1082	1663.09	2166.61	1663.06	2167.49	+0.03	−0.88
1083	−1641.10	−2160.07	−1640.54	−2160.24	+0.56	−0.17
1084	1639.96	1974.23	1640.12	1974.96	−0.16	−0.73
1085	1636.92	2005.00	1636.52	2005.35	+0.40	−0.35
1086	1633.17	1878.50	1632.93	1878.14	+0.24	+0.36
1087	1623.20	2305.62	1622.70	2306.04	+0.50	−0.48
1088	−1617.65	−2242.91	−1618.13	−2243.44	−0.48	−0.53
1089	1613.21	2231.35	1614.92	2030.45	−1.71	+0.90
1090	1557.59	2073.65	1557.03	2074.17	+0.56	−0.52
1091	1541.13	2251.31	1539.99	2250.84	+1.14	+0.47
1092	1538.83	1896.87	1539.43	1896.85	−0.60	+0.02
1093	−1531.79	−1960.76	−1531.59	−1960.43	+0.20	+0.33
1094	1505.92	1932.08	1506.35	1931.46	−0.43	+0.62
1095	1499.90	2243.25	1499.31	2243.75	+0.59	−0.50
1096	1486.22	1948.45	1485.23	1947.69	+0.99	+0.76
1097	1470.02	1950.22	1469.70	1958.84	+0.32	+0.38
1098	−1457.19	−1873.21	−1457.17	−1872.94	+0.02	+0.27
1099	1445.01	2062.15	1445.34	2061.95	−0.33	+0.20
1100	1439.76	2025.88	1438.77	2026.07	+0.99	−0.19
1101	1428.93	2040.49				
1102	1406.36	1960.21	1405.96	1960.25	+0.40	−0.04
1103	−1404.07	−2210.94	−1403.55	−2210.69	+0.52	+0.25
1104	1379.42	2033.58	1379.59	2033.09	−0.17	+0.49
1105	1376.00	2247.27	1376.23	2247.91	−0.23	−0.64
1106	1367.63	2104.88	1367.30	2104.84	+0.33	+0.04
1107	1367.01	2138.20	1366.92	2136.90	+0.09	+1.30

TABLE 14

SECTION XII. MEASURED COORDINATES — Continued

NO.	MAG.	PLATE III		PLATE V	
		x	y	x	y
		r	r	r	r
1108	13.4	−35.7611	−50.8194	−35.6948	−50.8535
1109	16.2	35.4358	57.4461	35.3788	57.5012
1110	16.8	34.0788	57.1591	34.0136	57.1872
1111	16.8	33.9901	52.2551		
1112	17.9	33.5866	58.1418	33.5224	58.1902
1113	15.9	−32.5796	−50.8308	−32.5176	−50.8768
1114	14.7	30.8258	56.6921	30.7701	56.7425
1115	14.5	30.5471	56.6024	30.4896	56.6352
1116	11.7	30.0127	51.9128	29.9461	51.9448
1117	14.2	29.9818	53.3941	29.9251	53.4320
1118	15.2	−29.8631	−54.7006	−29.7881	−54.7498
1119	15.5	29.8378	53.7031	29.7906	53.7588
1120	16.8	29.7573	58.6823	29.6966	58.7120
1121	16.5	29.5948	60.3376	29.5561	60.3742
1122	16.8	29.3374	60.1066	29.2964	60.1642
1123	11.2	−28.5724	−53.6321	−28.5241	−53.6692
1124	15.0	28.3758	59.0414	28.3101	59.0960
1125	14.2	27.5551	54.3146	27.4828	54.3592
1126	14.2	27.2451	54.8368	27.1976	54.8640
1127	14.7	26.4126	49.8766	26.3664	49.9082
1128	16.6	−26.3881	−52.7611	−26.3176	−52.8130
1129	13.7	26.0961	59.9948	26.0304	60.0257
19	11.2	25.6714	53.0151	25.6054	53.0380
1130	16.8	25.6238	59.8768	25.5556	59.9170
1131	15.2	25.4398	56.9696	25.3806	57.0142
1132	14.0	−24.9356	−58.1101	−24.8626	−58.1532
1133	17.9	24.8594	53.7651	24.7926	53.7962
1134	16.8	24.7804	55.9014	24.7076	55.9498
1135	14.0	24.6286	57.4686	24.5611	57.5002
1136	16.8	24.4508	54.1941	24.3876	54.2185
1137	17.9	−23.4481	−56.8628	−23.3938	−56.9562
1138	17.9	23.0658	57.2368	22.9951	57.2752
1139	17.9	22.8806	56.7511	22.8238	56.8038
1140	15.7	21.1294	49.1166	21.0628	49.1585
1141	16.8	21.0468	55.2294	21.0003	55.2898
1142	15.5	−21.0351	−50.0968	−20.9678	−50.1327
1143	16.6	20.7498	49.9146	20.7064	49.9542
1144	17.3	20.5136	51.8218	20.4378	51.8385
1145	13.7	20.4838	58.3996	20.4131	58.4395
1146	15.5	20.3308	55.7958	20.2666	55.8235

TABLE 14

SECTION XII. REDUCED COORDINATES — CONTINUED

NO.	PLATE III		PLATE V		V_X	V
	X	Y	X	Y	V−III	V−III
	″	″	′	″	″	″
1108	−1355.04	−1929.42	−1354.57	−1929.08	+0.47	+0.34
1109	1342.56	2180.64	1342.66	2181.11	−0.10	−0.47
1110	1291.09	2169.66	1290.87	2169.15	+0.22	+0.51
1111	1287.83	1983.72				
1112	1272.40	2206.88	1272.25	2207.16	+0.15	−0.28
1113	−1234.36	−1929.62	−1234.06	−1929.83	+0.30	−0.21
1114	1167.71	2151.71	1167.84	2152.16	−0.13	−0.45
1115	1157.14	2148.29	1157.20	2148.08	−0.06	+0.21
1116	1136.96	1970.45	1136.53	1970.22	+0.43	+0.23
1117	1135.76	2026.61	1135.75	2026.61	+0.01	0.00
1118	−1131.23	−2076.13	−1130.57	−2076.56	+0.66	−0.43
1119	1131.05	2038.31	1130.66	2038.90	+0.39	−0.68
1120	1127.13	2227.09	1127.15	2226.78	−0.02	+0.31
1121	1120.03	2289.83	1121.84	2289.80	−0.91	+0.03
1122	1111.17	2281.05	1111.98	2281.83	−0.81	−0.78
1123	−1082.29	−2035.53	−1082.62	−2035.54	−0.33	−0.01
1124	1074.72	2240.60	1074.56	2241.29	+0.16	−0.69
1125	1043.69	2061.33	1043.13	2061.66	+0.56	−0.33
1126	1031.92	2081.10	1032.32	2080.79	−0.40	+0.31
1127	1000.44	1892.98	1000.74	1892.86	−0.30	+0.12
1128	− 999.45	−2002.34	− 998.92	−2002.90	+0.53	−0.65
1129	988.22	2276.58	988.10	2276.44	+0.12	+0.14
19	972.26	2011.92	971.90	2011.49	+0.36	+0.43
1130	970.31	2272.07	970.09	2272.30	+0.22	−0.23
1131	963.39	2161.83	963.42	2162.24	−0.03	−0.41
1132	− 944.24	−2205.03	− 943.79	−2205.40	+0.45	−0.37
1133	941.44	2040.29	941.08	2040.21	+0.36	+0.08
1134	938.40	2121.28	937.88	2121.85	+0.52	−0.57
1135	932.61	2180.69	932.34	2180.63	+0.27	+0.06
1136	925.94	2056.53	925.73	2056.20	+0.21	+0.33
1137	− 887.84	−2157.63	− 888.06	−2159.96	−0.22	−2.33
1138	873.33	2171.78	873.04	2172.04	+0.39	−0.26
1139	866.32	2153.36	866.44	2154.16	−0.12	−0.80
1140	800.05	1863.77	799.56	1864.22	+0.49	−0.45
1141	796.79	2095.53	797.26	2096.68	−0.47	−1.15
1142	− 796.46	−1900.93	− 795.97	−1901.15	+0.49	−0.22
1143	785.64	1894.00	786.05	1894.37	−0.41	−0.37
1144	776.64	1966.29	775.99	1965.81	+0.65	+0.48
1145	775.37	2215.68	775.02	2216.08	+0.35	−0.40
1146	769.62	2116.95	769.54	2116.89	+0.08	+0.06

TABLE 14

SECTION XII. MEASURED COORDINATES—Continued

NO.	MAG.	PLATE III		PLATE V	
		x	*y*	*x*	*y*
		r	*r*	*r*	*r*
1147	16.8	−19.9616	−57.1151	−19.9388	−57.1672
1148	16.8	19.7831	56.4711	19.7478	56.5477
1149	16.8	19.6078	56.2091	19.5878	56.2240
1150	15.3	19.5574	49.4398	19.5076	49.4710
1151	16.8	19.3174	56.2681	19.2868	56.3072
1152	14.7	−19.2854	−51.8211	−19.2404	−51.8620
1153	17.9	18.9268	59.1444	18.8848	59.1580
1154	17.9			18.8773	58.5698
1155	17.9	18.7161	56.3498	18.6128	56.3682
1156	16.8	18.2691	55.9831	18.2051	56.0218
1157	14.2	−1.80371	−56.4954	−17.9611	−56.5070
1158	16.8	17.7108	52.7528	17.6451	52.7527
1159	15.5	17.2314	57.1600	17.1056	57.1752
1160	14.5	17.0108	54.3428	16.9401	54.3705
1161		16.0321	49.4358	16.8691	49.4452
1162	14.2	−16.8168	−52.5561	−16.7631	−52.5732
1163	17.9	16.7280	54.0951	16.6881	54.1142
1164	16.8	15.9904	50.7864	15.9526	50.8200
1165	13.5	15.5856	50.9501	15.5473	50.9657
1166	15.5	14.7444	59.3371	14.6726	59.3605
1167	16.8	−14.6156	−52.4008	−14.5713	−52.4772
1168	13.7	14.2056	57.2571	14.2203	57.2005

SECTION XIII. MEASURED COORDINATES

1169		−47.7113	−36.6086	−47.6545	−36.6720
1170	16.2	47.3409	39.4812	47.2970	39.5112
1171	16.8	46.5800	42.2664	46.5265	42.2862
1172	16.1	46.2007	36.1292	46.1632	36.1620
8	9.1	46.1552	46.0269	46.1158	46.0525
1173	14.9	−45.3057	−47.2726	−45.2572	−47.3042
1174	13.7	44.9275	39.6832	44.8800	39.7098
1175	16.8	44.8840	37.9444	44.8400	37.9895
1176	15.5	44.2207	44.4156	44.1788	44.4303
1177	14.7	42.9242	44.9019	42.8855	44.9200

TABLE 14

SECTION XII. REDUCED COORDINATES

NO.	PLATE III		PLATE V		V_X	V_Y
	X	Y	X	Y	V−III	V−III
	″	″	″	″	″	″
1147	− 755.59	−2166.94	− 757.02	−2167.82	−1.43	−0.88
1148	748.83	2142.51	749.77	2144.32	−0.94	−1.81
1149	742.18	2132.56	743.79	2132.04	−1.61	+0.52
1150	740.42	1875.91	740.58	1876.01	−0.16	−0.10
1151	731.17	2134.78	732.38	2135.19	−1.21	−0.41
1152	− 730.05	−1966.18	− 730.47	−1966.65	−0.42	−0.47
1153	716.29	2243.80	717.06	2243.25	−0.77	+0.55
1154			716.87	2220.95		
1155	708.36	2137.83	706.81	2137.47	+1.55	+0.36
1156	691.41	2123.90	691.25	2124.32	+0.16	−0.42
1157	− 682.60	−2143.30	− 682.10	−2142.71	+0.50	+0.59
1158	670.30	2001.38	670.07	2000.35	+0.23	+1.03
1159	652.02	2168.44	653.07	2168.01	−1.05	+0.43
1160	643.71	2061.61	643.69	2061.66	+0.02	−0.05
1161	640.83	1875.57	640.60	1874.92	+0.23	+0.65
1162	− 636.39	−1993.86	− 636.51	−1993.51	−0.12	+0.35
1163	633.01	2052.20	633.79	2051.93	−0.78	+0.27
1164	605.08	1926.70	605.75	1927.01	−0.67	−0.31
1165	589.53	2274.33	590.48	2273.74	−0.95	+0.59
1166	557.04	2250.80	557.30	2250.76	+0.34	+0.04
1167	− 552.90	−1990.08	− 553.38	−1989.78	−0.48	+0.30
1168	540.66	2171.90	540.46	2172.26	+0.20	−0.36

SECTION XIII. REDUCED COORDINATES

1169	−1810.48	−1388.50	−1809.93	−1389.72	+0.55	−1.13
1170	1796.53	1497.55	1796.55	1497.43	−0.02	+0.12
1171	1767.74	1603.20	1767.51	1602.72	+0.23	+0.48
1172	1753.16	1370.41	1753.33	1370.41	−0.17	0.00
8	1751.73	1745.83	1752.17	1745.60	−0.44	+0.23
1173	−1719.55	−1793.08	−1719.69	−1793.10	−0.14	−0.02
1174	1704.07	1505.22	1704.88	1505.02	+0.09	+0.20
1175	1703.27	1439.26	1703.25	1439.76	+0.02	−0.50
1176	1678.30	1684.72	1678.59	1684.10	−0.29	+0.62
1177	1629.13	1703.16	1629.57	1703.05	−0.44	+0.11

TABLE 14

SECTION XIII. MEASURED COORDINATES — CONTINUED

NO.	MAG.	PLATE III		PLATE V	
		x	y	x	y
		r	r	r	r
1178	17.9	−42.5530	−37.2462	−42.4995	−37.2658
1179	13.5	42.1720	36.2322	42.1332	36.2575
1180	14.2	42.1370	46.3092	42.0830	46.3262
1181	16.8	42.1290	40.2089	42.1072	40.2012
1182	14.2	41.6995	37.3472	41.6498	37.3742
1183	15.0	−41.2332	−44.1446	−41.2078	−44.1810
1184	13.3	40.2497	44.2274	40.2115	44.2562
1185	14.5	39.9270	45.8359	39.8865	45.8688
1186	16.2	39.3220	35.9592	39.2620	35.9752
1187	15.7	39.2575	43.1619	39.2018	43.1710
1188	16.2	−39.0087	−41.3659	−38.9618	−41.4055
1189	15.5	38.8580	35.2367	38.7638	35.2708
1190	17.9	38.5330	39.1140	38.4952	39.0742
1191	16.8	38.5127	38.3506	38.4088	38.3790
1192	14.7	38.4412	37.7034	38.3010	37.8040
1193	15.2	−38.4200	−44.1009	−38.3768	−44.1190
1194	19.0	38.2000	40.5329	38.1242	40.5525
1195	19.0	38.1500	39.9072	38.0662	39.9585
1196	14.9	38.0614	37.8429	38.0255	37.8910
1197	15.2	38.0612	46.0616	37.9050	46.0838
1198	14.2	−37.8407	−38.9459	−37.7040	−38.9722
1190	15.2	37.6880	43.7342	37.6460	43.7582
1200	19.0	37.5452	40.0912	37.5190	40.1275
1201	14.5	37.4020	43.0336	37.4405	43.0422
1202	19.0	36.5709	40.2776	36.5190	40.3128
1203	19.0	−36.2472	−39.8474	−36.2320	−39.8578
1204	14.5	36.0122	42.6396	35.9552	42.6888
1205	15.3	35.9882	43.6329	35.9385	43.6435
1206	14.7	35.9485	38.9916	35.9120	39.0245
1207	19.0	35.9385	40.2444	35.8485	40.2785
1208	19.0	−35.8742	−43.3056	−35.8005	−43.2982
1209	19.0	35.8657	39.5032	35.8162	39.5170
1210	19.0	35.8437	39.8907	35.8030	39.9382
1211	15.7	35.0445	44.7316	35.5820	44.7635
1212	19.0	35.4737	41.9629	35.4132	41.9460
1213	19.0	−35.4700	−39.3416	−35.4390	−39.2825
1214	15.7	35.4082	37.1509	35.3608	37.1790
1215	19.0	35.3630	43.5442	35.3208	43.5688
1216	15.7	35.2620	41.0432	35.2232	41.0638
1217	19.0	35.2530	41.6100	35.2245	41.5605

TABLE 14

SECTION XIII REDUCED COORDINATES — CONTINUED

No.	PLATE III		PLATE V		V_X	V_Y
	X	Y	X	Y	V − III	V − III
	"	"	"	"	"	"
1178	−1614.82	−1412.78	−1614.43	−1412.36	+0.39	+0.42
1179	1600.34	1374.32	1600.47	1374.12	−0.13	+0.20
1180	1599.31	1756.54	1599.22	1756.07	+0.09	+0.47
1181	1508.83	1525.16	1599.74	1523.72	−0.01	+1.44
1182	1582.45	1416.61	1582.20	1416.49	+0.25	+0.12
1183	−1504.96	−1674.44	−1565.88	−1674.71	−0.92	−0.27
1184	1527.66	1677.58	1528.09	1677.58	−0.43	0.00
1185	1515.46	1738.59	1515.87	1738.76	−0.41	−0.17
1186	1492.22	1363.97	1491.54	1363.47	+0.68	+0.50
1187	1489.99	1637.17	1489.72	1636.44	+0.27	+0.73
1188	−1480.49	−1569.05	−1480.50	−1569.47	−0.01	−0.42
1189	1474.59	1336.56	1472.59	1336.76	+2.00	−0.20
1190	1462.38	1483.65	1462.65	1481.04	−0.27	+2.61
1191	1461.59	1454.68	1461.61	1454.67	−0.02	+0.01
1192	1458.86	1433.54	1458.62	1432.86	+0.24	+0.68
1193	−1458.24	−1672.78	−1458.49	−1672.42	−0.25	+0.36
1194	1449.79	1537.45	1448.68	1537.13	+1.11	+0.32
1195	1447.88	1517.13	1446.44	1514.60	+1.44	+2.53
1196	1444.45	1435.42	1444.76	1436.17	−0.31	−0.75
1197	1444.69	1747.15	1444.14	1746.96	+0.55	+0.19
1198	−1436.11	−1477.26	−1436.05	−1477.19	+0.06	−0.07
1199	1430.46	1658.88	1430.75	1658.75	−0.29	+0.13
1200	1424.94	1520.70	1425.69	1521.02	−0.75	−0.32
1201	1423.01	1632.30	1422.91	1631.59	+0.10	+0.71
1202	1387.98	1527.77	1387.77	1528.07	+0.21	−0.30
1203	−1375.69	−1511.45	−1376.86	−1510.82	−1.17	+0.63
1204	1366.86	1617.36	1366.54	1618.22	+0.32	−0.86
1205	1365.98	1655.03	1365.97	1654.43	+0.01	+0.60
1206	1364.34	1478.90	1364.66	1479.21	−0.32	−0.22
1207	1363.99	1526.51	1362.34	1526.79	+1.65	−0.28
1208	−1301.65	−1642.62	−1360.71	−1641.34	+0.94	+1.28
1209	1361.21	1498.39	1361.06	1497.90	+0.15	+0.49
1210	1360.50	1513.09	1360.50	1513.88	−0.20	−0.79
1211	1352.98	1696.71	1352.52	1696.93	+0.46	−0.22
1212	1346.41	1591.69	1345.93	1590.05	+0.48	+1.64
1213	−1346.19	−1492.27	−1346.74	−1489.01	−0.55	+3.26
1214	1343.78	1409.40	1343.64	1409.22	+0.14	+0.18
1215	1342.26	1651.67	1342.54	1651.61	−0.28	+0.06
1216	1338.35	1556.81	1338.67	1556.59	−0.32	+0.22
1217	1338.03	1578.31	1338.75	1575.43	−0.72	+2.88

TABLE 14

SECTION XIII. MEASURED COORDINATES — CONTINUED

NO.	MAG.	PLATE III		PLATE V	
		x	y	x	y
		r	r	r	r
1218	19.0	−35.2370	−39.5022	−35.2835	−39.5388
1219	19.0	35.2365	−42.9726	35.2235	−42.9312
1220	16.8	35.1892	−45.3442	35.1485	−45.3370
1221		34.8945	−42.4376		
1222	16.8	34.1627	−43.7009	34.1080	−43.7438
1223	17.3	−33.7707	−42.8262	−33.7012	−42.8460
1224	16.8	33.3675	−43.4414	33.3102	−43.4415
1225	15.5	33.2617	−46.4892	33.2060	−46.4982
1226	12.6	33.2144	−36.7376	33.1808	−36.7530
1227	14.5	28.4954	− 3.1556	28.4690	− 3.1985
1228	16.8	−28.3897	− 2.0962	−28.3852	− 2.1278
1229	14.3	28.3662	+ 4.3501	28.3645	+ 4.3035
1230	15.7	27.4280	+ 3.5623	27.4118	+ 3.5225
1231	15.5	27.1747	− 4.8164	27.1570	− 4.8592
1232	17.9			26.7515	− 3.1445
1233	17.9	−26.6904	+ 5.7121	−26.6825	+ 5.6600
1234	19.0	26.5187	− 4.0044	26.5255	− 4.0168
1235	17.5	26.4014	− 1.8646	26.4382	− 1.9025
1236	19.0	26.2652	− 1.7782		
1237	13.9	25.6472	+ 7.0566	25.6352	+ 7.0050
1238	16.8	−25.6007	− 0.8242	−25.5945	− 0.8700
1239	13.5	25.3940	− 5.7799	25.3665	− 5.8095
1240	14.5	25.3544	− 7.0372	25.3335	− 7.0838
1241	16.2	25.1915	− 3.9696	25.1620	− 4.0210
1242	14.6			25.1140	+ 5.5532
1243	16.8	−24.1762	+ 9.3528	−24.1738	+ 9.3105
1244	16.8	24.7597	+ 6.4706	24.7702	+ 6.4438
1245	13.5	23.9097	+ 1.7081	23.8952	+ 1.6885
1246	15.7	23.8464	− 5.0379	23.8152	− 5.0928
1247	15.2	23.5547	+10.5366	23.5610	+10.4830
1248	16.8	−23.3187	+ 1.8543	−23.3240	+ 1.8068
1249	13.7	23.1872	+ 1.4198	23.1792	+ 1.3665
1250	17.1	23.0795	+ 3.6459	23.0685	+ 3.6138
1251	19.0	23.0642	+10.1583	23.0585	+10.1132
1252	16.2	22.9120	+ 5.4921	22.9020	+ 5.4482
1253	16.8	−22.7400	+ 6.0963	−22.7385	+ 6.0692
1254	16.8	22.6887	− 2.2429	22.6685	− 2.2902
1255	15.7	22.4324	+ 8.0318	22.4325	+ 8.8918
1256	14.2	22.3724	− 4.7344	22.3505	− 4.7675
1257	15.7	22.2877	− 7.1136	22.2538	− 7.1445

TABLE 14

SECTION XIII. REDUCED COORDINATES — CONTINUED

NO.	PLATE III		PLATE V		V_X	V_Y
	X	Y	X	Y	V−III	V−III
	″	″	″	″	″	″
1218	−1337.36	−1498.36	−1340.86	−1498.74	−3.50	−0.38
1219	1337.45	1629.99	1338.80	1627.43	−1.35	+2.56
1220	1335.72	1719.94	1336.12	1718.69	−0.40	+1.25
1221	1324.46	1609.70				
1222	1296.73	1657.61	1296.54	1658.28	+0.19	−0.67
1223	−1281.84	−1624.44	−1281.05	−1624.23	+0.79	+0.21
1224	1266.56	1647.77	1266.26	1646.82	+0.30	+0.95
1225	1262.64	1763.38	1802.51	1702.78	+0.13	+0.60
1226	1260.55	1393.50	1260.92	1393.11	−0.37	+0.39
1227	1080.53	119.73	1080.00	120.35	+0.53	−0.62
1228	−1076.49	− 79.55	−1076.75	− 79.73	−0.26	−0.18
1229	1075.40	+ 164.96	1075.55	+ 164.23	−0.15	−0.73
1230	1039.84	+ 135.07	1039.46	+ 134.59	+0.38	−0.48
1231	1030.48	182.73	1030.34	− 183.37	+0.14	−0.64
1232			1014.85	− 118.33		
1233	−1011.79	+ 216.62	−1011.66	+ 215.66	+0.13	−0.96
1234	1005.57	− 151.93	1006.33	− 151.43	−0.76	+0.50
1235	1003.33	− 70.77	1002.89	− 71.23	+0.44	−0.46
1236	995.89	− 67.49				
1237	972.15	+ 301.75	971.79	+ 300.80	+0.36	−0.95
1238	− 970.65	− 31.31	− 970.81	− 32.08	−0.16	−0.77
1239	962.96	− 219.28	962.49	− 219.46	+0.47	−0.18
1240	961.49	− 260.97	961.32	− 267.80	+0.17	−0.83
1241	955.22	− 150.61	954.01	− 151.62	+0.61	−1.01
1242			952.17	+ 211.57		
1243	− 916.31	+ 354.71	− 916.26	+ 354.42	+0.05	−0.29
1244	938.53	+ 245.38	939.07	+ 245.35	−0.54	−0.03
1245	906.43	+ 64.74	906.19	+ 64.94	+0.24	+0.20
1246	904.23	− 191.13	903.00	− 192.30	+0.63	−1.17
1247	892.69	+ 399.61	892.94	+ 398.55	−0.25	−1.06
1248	− 884.00	+ 70.29	− 884.52	+ 69.42	−0.52	−0.87
1249	879.03	+ 53.81	879.05	+ 52.71	−0.02	−1.10
1250	874.87	+ 138.23	874.71	+ 137.96	+0.16	−0.27
1251	874.10	+ 385.26	873.90	+ 384.51	+0.20	−0.75
1252	868.47	+ 208.39	868.27	+ 207.54	+0.20	−0.85
1253	− 861.02	+ 231.19	− 862.03	+ 231.09	−0.11	−0.10
1254	860.23	− 85.12	859.92	− 86.01	+0.31	−0.89
1255	850.17	338.74	850.24	+ 338.16	−0.07	−0.58
1256	848.30	− 179.62	848.02	− 179.99	+0.28	−0.37
1257	845.16	− 269.87	844.50	− 270.17	+0.66	−0.30

TABLE 14

SECTION XIII. MEASURED COORDINATES—CONTINUED

NO.	MAG.	PLATE III		PLATE V	
		x	*y*	*x*	*y*
		r	*r*	*r*	*r*
1258	14.7	−22.2835	+ 9.6284	−22.2695	+ 9.5908
1259	16.8	22.1237	− 2.3642	22.1225	− 2.4075
1260	18.4	21.9364	+ 0.0103	21.9160	− 0.0392
1261	16.2	21.6600	+ 2.7953	21.6295	+ 2.7712
1262	16.2	21.2755	+ 6.2578	21.2908	+ 6.2182
1263	18.4	−21.2484	+ 3.7762	−21.2370	+ 3.7418
1264	15.7	21.1164	+ 2.1018	21.1062	+ 2.0502
1265	13.1	20.9080	− 5.6540	20.8800	− 5.6958
1266	16.2	20.8277	+ 6.0876	20.8208	+ 6.0335
1267	14.4	20.0727	+ 6.7321	20.0332	+ 6.7012
1268	17.5	−19.2957	+ 3.3471	−19.3310	+ 3.3415
1269	15.5	19.2374	+ 6.7078	19.2320	+ 6.6440
1270	15.1	19.1742	− 1.9646	19.1422	− 1.9955
1271	14.7	18.9390	+ 4.3736	18.9272	+ 4.3450
1272	17.1	18.6597	+ 2.8116	18.6570	+ 2.7542

TABLE 14

SECTION XIII. REDUCED COORDINATES. CONTINUED

NO.	PLATE III		PLATE V		V_X	V_Y
	X	Y	X	Y	V−III	V−III
	″	″	″	″	″	″
1258	− 844.50	+ 305.16	− 844.01	+ 364.67	+0.49	−0.49
1259	838.80	− 89.72	839.22	− 90.48	−0.42	−0.76
1260	831.62	+ 0.34	831.23	− 0.64	+0.39	−0.98
1261	821.05	+ 105.98	820.18	+ 105.96	+0.87	−0.02
1262	806.30	+ 237.31	807.11	+ 236.72	−0.75	−0.59
1263	− 805.41	+ 143.18	− 805.23	+ 142.77	+0.18	−0.41
1264	800.45	+ 79.67	800.37	+ 78.60	+0.08	−1.07
1265	792.78	− 214.53	792.30	− 215.24	+0.48	−0.71
1266	789.38	+ 230.86	789.29	+ 229.70	+0.09	−1.16
1267	760.72	+ 255.30	759.37	+ 255.01	+1.35	−0.29
1268	− 731.35	+ 126.91	− 732.95	+ 127.55	−1.60	+0.64
1269	729.03	+ 254.38	728.98	+ 252.82	+0.05	−1.56
1270	726.90	− 74.57	726.14	− 74.91	+0.76	−0.34
1271	717.78	+ 165.84	717.57	+ 165.61	+0.21	−0.23
1272	707.24	+ 106.60	707.43	+ 105.26	−0.19	−1.34

THE REGISTRATION OF EARTHQUAKES AT THE DETROIT OBSERVATORY, ANN ARBOR, 1916-1921

By W. CARL RUFUS

The form of record previously used in these Publications has been followed. Columns one and two give the serial number of the shock and the date of its occurrence. The third column indicates the component and the instrument with which it was recorded. B-EW and B-NS refer respectively to the east and west component and the north and south component of the Bosch instruments. W-EW and W-NS refer to the corresponding components recorded with the Wiechert horizontal seismograph. The use of the Wiechert vertical instrument has been discontinued on account of its inefficiency.

The symbols at the head of columns four to ten inclusive are as follows:

P, time of arrival of longitudinal waves.
S, time of arrival of transverse waves.
L, time of arrival of long or surface waves.
M, time of maximum.
F, end of record on seismogram.
A, greatest excursion of the pen from the zero line.
Δ, distance from epicenter to station, determined from records.

In the remarks following the record some additional symbols have been used corresponding with those adopted by the International Seismological Association.

O, time of disturbance at epicenter.
PR_1, time of arrival of once reflected longitudinal waves.
PR_2, time of arrival of twice reflected longitudinal waves.
SR_1, time of arrival of once reflected transverse waves.
SR_2, time of arrival of twice reflected transverse waves.

All times are given in Greenwich Civil Time, midnight to midnight.

The magnifications and periods of the instruments are as follows;

	MAGNIFICATION	PERIOD
B — EW	40	11.5 sec.
B — NS	50	12.0
W — EW	80	4.9
W — NS	80	6.0

Dr. Paul W. Merrill read the seismograms and kept the record from January 1, 1916 to May 31, 1916; Dr. C. C. Kiess from June 1, 1916 to June 19, 1917; and the writer with the assistance of Mr. H. R. Carpenter from June 20, 1917 to December 31, 1921.

REMARKS

177. On B — EW P is about at the beginning of the sheet. Waves almost perfectly regular and smooth for 15 minutes at M. W — NS is quite insensitive. Difficult to place L in this quake. F runs into feeble microseisms.

179. Another group of long waves appears on B — EW and W — EW at $7^h\ 41^m$.

181. Long waves in midst of microseisms. Plain on W — EW, probably a real quake.

182. Δ is determined from the interval L — S.

Jan. 26. Slight shock as sheets were being changed, $13^h\ 25^m$.

Jan. 31. Flat distant shock. 18 19 hrs.

Feb. 1. Flat distant shock, $8^h\ 30^m$, on all components.

1183. The phases of this shock as recorded appear discordant. A reexamination of the record by the writer gave the following results.

	W — EW		W — NS	
P	22^h	2.0^m	22^h	2.1^m
S	22	10.4	22	10.6
S R_1	22	15.2		
S R_2	22	17.7		
L	22	22.8	22	22.7

On this interpretation the distance is about 7.2 mgm.)

184. The short waves are superposed on L.

185. Long flat shock. Phases not well marked.

NO.	DATE	INST COMP.	P	S	I	M	F	V	Δ
	1910		h m	h m	h m	h m	h m	mm.	mgm
177	Jan. 1	B — EW	13 40?	13 50.5	14 10?	14 24.0	16 0	25.0	10.5
		B — NS		13 50.3	14 10?	14 24.6	16 0	19.0	
		W — EW	13 37.1	13 50.3		14 25.0	16 4 0	5 4	
		W — NS				14 24.8	14 52	1.0	
178	Jan. 13	B — EW			Trace				
		B — NS	6 40.0?	6 46.2?		6 58.0		0.2	
		W — EW				6 57 8		0.2	
179	Jan. 13	B — EW			7 23.7	7 30.4		3.8	
		B — NS	7 7.7?		7 24.8	7 29.4	8 5	1.4	
		W — EW		7 12.0?	7 24.2	7 30.2	8 0	1.0	
		W — NS			7 24.2	7 29.7	7 52	0.4	
180	Jan. 13	B — EW			8 59.5?	9 20.5	11 0	3.8	
		B — NS	8 30.0?		8 58.8?	9 30.4	Micros?	5.0	
		W — EW		8 42.4?	8 59.7	9 20.7	11 0	1.8	
		W — NS				9 30.4	10 0	0.6	
181	Jan. 19	B — EW			20 0?	20 5	20 12	0.3	
		B — NS			Trace				
		W — EW			20 0	20 5	20 20	0.2	
182	Jan. 24	B — EW		7 25.6	7 35.2	7 40	8 1	0.6	7.7?
		B — NS	7 10.1?	7 20.3	7 35.5	7 44	8 25	1.0	
		W — EW	Record in-		7 30.3	7 40	8 21	0.6	
		W — NS	distinct		Slight trace				
183	Feb. 6	B — EW	22 10.4?	22 17.7?	22 22.8	22 31.8	23 25	5.0	
		B — NS	22 10.0		22 22.7	22 28.3	23 23	2.0	
		W — EW	22 10.4	22 17.8?	22 22.7	22 31.7	23 28	1.0	
		W — NS				22 28.0		0.2	
184	Feb. 15	B — EW		11 50.1	11 56.8	11 58.5	12 27	4.0	4.5
		B — NS	11 43.8	11 50.1?	11 57.0	12 2.4	12 26	2.0	
		W — EW		11 50.1	11 56.9	11 59.0	12 28	6.0	
		W — NS			Trace only				
185	Feb. 20	B — EW		18 4.8?	18 14.5	18 31	19 12	1.0	
		B — NS		18 4.8	18 14.5	18 25	19 14	1.4	
		W — EW		18 4.8	18 14.5	18 31	19 26	1.0	
186	Feb. 27	B — EW	20 27.4	20 34.8	20 38.1	20 40.2		37.0	3.9
		B — NS	20 27.5	20 32.9	20 38.0	20 45.0		Off paper	
		W — EW	20 27.5	20 34.8	20 38.4	20 40		4.0	
		W — NS	20 27.0	20 33.0?	20 37.4	20 40		1.0	
187	Mar. 12	B — EW				7 48			
		B — NS				7 47			
		W — EW				7 47			

NO.	DATE	INST. COMP.	P	S	L	M	F	A	Δ
	1916		h m	h m	h m	h m	h m	mm.	mgm.
188	Mar. 16	B — EW				23 4		0.4	
		B — NS				23 2		0.4	
		W — EW				23 2		0.4	
		W — NS				Trace			
189	Mar. 28	B — EW				7 55			
		B — NS				7 57			
		W — EW				7 57			
190	Mar. 29	B — EW				19 11			
		B — NS				19 12			
		W — EW				19 11			
191	Mar. 31	B — EW		11 27.8		11 30.6	11 51	6.0	
		B — NS		11 27.6	11 30.2	11 31.0	11 51	3.2	
		W — EW		11 27.9		11 30.6	11 44	2.0	
		W — NS				11 31.2		0.2	
192	Apr. 2	B — EW			8 39.6	8 40.2	8 51	0.4	
		B — NS			8 39.7	8 40.0	8 53	0.6	
		W — EW			8 38.8	8 40.5	8 50	0.4	
193	Apr. 7	B — EW	9 45.5			10 52.1	11 21	2.4	
		B — NS	9 46.2			10 53.8	11 20	0.8	
		W — EW	9 45.7	10 1.4?		10 52.0	11 23	0.6	
194	Apr. 11	B — EW				3 57			
		B — NS				3 56			
		W — EW				3 57			
195	Apr. 15	B — EW			14 3				
		B — NS			14 5				
		W — EW			14 2				
196	Apr. 18	B — EW	4 11.2	4 18.8	4 32.1	4 33.3	5 22	4.8	6.6
		B — NS	4 11.1	4 18.8	4 29.6?	4 32.2	5 12	4.6	
		W — EW	4 11.1	4 18.8		4 33.4	5 20	3.0	
		W — NS	4 11.3	4 18.7		4 33.4			
197	Apr. 24	B — EW	4 32.5	4 36.7?	4 37.6	4 38.1	5 20	6.8	
		B — NS	4 32.3	4 37.2	4 38.0?	4 39.0	5 20	9.0	
		W — EW	4 32.6	4 37.0?		4 39.0	5 16	2.0	
		W — NS	4 32.7	4 37.4					
198	Apr. 24	B — EW	6 8.5		6 15.8	6 26.0	7 13	31.0	
		B — NS	6 7.9	6 13.5	6 18.1	6 22.0	7 20	47.4	
		W — EW	6 8.5		6 16.1	6 26.0	7 23	3.4	
		W — NS			6 20.0	6 22.5	6 27	0.6	
199	Apr. 26	B — EW	2 27.9	2 31.1?	2 35.3	2 36.2	3 15	32.2	
		B — NS				2 42.1	3 22	5.6	
		W — EW	2 28?	2 33.3	2 35.6	2 39.0	3 14	3.0	
		W — NS				2 42.0			

NO.	DATE	INST. COMP.	P	S	L	M	F	A	Δ
	1916		h m	h m	h m	h m	h m	mm.	mgm.
200	Apr. 26	B — EW				18 41			
		B — NS				18 53			
		W — EW				18 41			
201	Apr. 26	B — EW				19 37			
		B — NS				19 42			
		W — EW				19 38			
202	May 10	B — EW	21 48.9	21 51.1	21 53.1	21 55.9	22 12	4.8	
		W — EW	21 48.0	21 51.1	21 53.5	21 55.8	22 6	1.4	
203	May 11	B — EW			10 19.0	10 19.2	11 36	1.6	
		B — NS			10 19.4	10 20.2		9.4	
		W — EW			10 19.3	10 19.8	11 41	1.0	
		W — NS				10 20.4			
204	May 26	B — EW				9 13			
		W — EW				Trace			
205	June 2	B — EW	14 3.8	14 9.0	14 10.3	14 10.4	14 23.0	0.5	3.0
		B — NS	14 3.8				14 33.0		
		W — EW	14 3.0						
		W — NS	14 3.0						
206	June 25	B — EW	17 34.8				17 43.8		
		B — NS	17 34.8				17 43.3		
207	June 30	B — EW	3 13.7				3 44.9	1	
		B — NS	3 13.4	3 16.8		3 20.0	3 45.2	3	2.4
		W — EW	3 13.4	3 16.8		3 20.1		0.5	2.4
208	Sept. 23	B — EW	5 49.0	5 53.7	5 55.5	5 56.2	6 6.4	0.5	2.4
		B — NS	5 48.5	5 53.4		6 2.2	6 11.4	0.75	3.0
		W — EW	5 48.5	5 53.5			6 11.0	< 0.5	4.0
209	Oct. 18	B — EW	22 5.3		22 6.6	22 6.8	22 10.2	1	0.4
		B — NS	22 5.8		22 6.8		22 10.3	< 0.5	0.3
		W — EW	22 5.9			22 6.9		2.5	
		W — NS	22 5.8	22 6.5	22 6.9	22 7.0	22 9.9	0.5	0.3
210	Nov. 10	B — EW	9 24.4	9 26.1	9 27.5	9 28.0	9 41.0	0.5	1.0
		B — NS	9 24.0			9 26.4	9 38.2	small	
		W — EW	9 24.3	9 26.1	9 27.5	9 27.9	9 41.0	0.5	1.0
211	Nov. 21	B — EW	6 33.4	6 36.6	6 41.1	6 43.2	6 60.4	0.5	2.5
		B — NS	6 34.1			6 46.6	6 59.2	small	
		W — EW	6 34.0	6 36.6	6 42.0	6 43.0	6 50.6	0.5	2.5
212	Nov. 30	B — EW	3 22.5	3 27.0	3 30.7	3 35.7	4 4.2	1	2.8
		B — NS	3 22.6	3 27.1	3 31.2		4 4.6	small	3.0
		W — EW	3 22 ±	3 27.1	3 30.8	3 34.6	4 4.5	small	2.3
		W — NS	No trace						

No	DATE	INST. COMP	P	S	L	M	F	A	Δ
	1917		h m	h m	h m	h m	h m	mm.	mgm.
213	Jan. 30	B — EW	3 55.3	3 4.4	3 18.1	3 { 22.6 / 26.5	5 9.7	25	7.7
		B — NS	3 55.6	3 4.4	3 18.2	3 29.4	5 4.0	32	7.7
		W — EW	3 55.4	3 4.4	3 18.1	3 21.5	5 8.9	4	7.7
		W — NS			3 19.3				
214	Feb. 20	B — NS	19 34.3	19 36.2	19 37.5	19 43.5	21 0±	60	1.0
		W — EW	19 34.0		19 38.1	19 42.0	21 0±	33	
		W — NS	19 34.1		19 41.4?				
215	Apr. 9	B — EW	20 54.2±						
		B — NS	20 54.2±			20 55.3			
		W — EW	20 54.2±			20 55.0			
		W — NS	20 54.2±			20 55.0			
216	Apr. 28	B — EW	16 17.1		16 17.5	16 17.6	16 20.3	1	0.1±
		B — NS	16 17.2±						
		W — EW	16 17.0		16 17.5	16 17.6	16 18.9	2	0.1±
217	May 1	B — NS	18 46.0	18 50.6	19 22.3	19 30.9	21 1.4	15	11.6
		W — EW	18 46.0	18 55.7	19 22.2	19 30.4	20 59.2	3	11.5
218	May 9	B — EW	16 53.3				17 9.8		
		B — NS	16 45.1				17 8.3		
		W — EW	16 53.0				17 8.0		
219	May 16	W — EW	14 57.7	17 19	17 54.5		19 7.0		
220	May 31	B — EW	8 56.7	9 3.7	9 13.1	9 17.8	10 10.0	7	5.3
		B — NS	8 56.9	9 4.6	9 13.5	9 17.3	10 10.0	2	5.4
		W — EW	8 56.4	9 3.4	9 13.4		10 15.0	0.5	
221	June 1	B — EW	17 2.5				17 13.0		
		B — NS	17 2.8				17 10.5		
		W — EW	17 2.6				17 47.5		
222	June 8	B — EW	1 1.2	1 2.9	1 6.0	1 8.8	2 3.2	12	1.4
		W — EW	1 1.1	1 3.1	1 6.1	1 8.2	1 59.4	1	1.6
223	June 11	B — EW	4 42.2				5 25.7		
		B — NS	4 48.6				5 13.7		
		W — EW	4 49.2				5 17.9		
224	June 24	B — EW			20 13.8	20 15.1	21 10	0.3	
		B — NS				20 15.4		0.2	
		W — EW			20 13.3	20 14.6		0.1	
225	June 26	B — NS	6 4.4	6 15.0	6 37.3	6 44.4	8 19.7	11.0	10.9
		W — NS			6 37.0	6 43.5		0.2	
226	June 27	W — EW		12 49.1?	12 53.7	12 56.0		0.3	

NO.	DATE	INST. COMP.	P	S	I	M	L	V	Δ
	1917		h m	h m	h m	h m	h m	mm	mgm
227	June 29	B — EW				16 25.0		0.5	
		B — NS		16 12.8?		16 25.4		0.3	
		W — EW				16 24.5		0.2	
228	July 4	B — NS				1 12.5			
		W — EW				1 18.5			
229	July 13	B — EW				5 24.0			
230	July 20	B — EW				15 0.1			small
		W — EW				14 59.5			
231	July 21	B — EW				18 41.8		2.4	
232	July 21	B — EW			23.9?	21 24.5		15.1	
233	July 25	B — EW		3 34.0	47.0	3 53.7		0.2	
		B — NS				3 52.6			
		W — EW		3 33.3	47.6	3 [illegible]0.3		0.1	
234	July 27	B — EW	1 7.8	1 12.4	18.1	1 21.5	3 40	17.3	3.4
		B — NS	1 8.0	1 12.6	1 17.9	1 21.6	3 45	2.8	
		W — EW	<1 9.0	1 12.7	1 18.2	1 21.8	2 1	1.5	
235	July 27	B — EW		3 13.6					
		B — NS				3 40.2			
236	July 29	B — EW	22 19.0?			22 59.7	23 16	0.2	
		W — EW				22 52.0		0.2	
237	Aug. 5	B — EW			16 48.4	17 1.5	18 3	0.3	
		B — NS				17 1.4		0.1	
238	Aug. 30	B — EW	3 32.3	3 37.2	3 40.8	3 45.7	4 6.5	0.2	
		W — EW		3 37.7	3 41?	3 41.0		0.1	
239	Aug. 30	B — EW	4 27.6		4 46.0	5 18.0	6 1	0.3	
		W — EW	4 27.0			5 16.0	6 0	0.1	
240	Aug. 31	B — EW	11 40?	11 40.6	11 53.6	11 58.8	13 19.5	2.0	4.6
		W — EW	11 41?	11 47.0	11 54.0	11 59.0	13 +	0.9	
241	Sept. 20	B — EW			4 0.3		4 27.0	0.2	
242	Oct. 19	B — EW	16 41.5	16 40.1	16 55.0	16 56.1	17 37.5	0.5	
		B — NS	16 42.8	16 48.4	16 55.3	16 58.0	17 0.8	0.3	
243	Oct. 22	B — EW		7 33.6?	7 50.4	7 58.3		0.2	
		B — NS			7 58.0	7 47.0			
244	Nov. 4	B — EW				13 30		0.2	
		W — EW		13 20.8?		13 34		0.1	

NO.	DATE	INST. COMP.	P	S	L	M	F	A	Δ
	1917		h m	h m	h m	h m	h m	mm.	mgm.
245	Nov. 7	B — EW						0.5	
		B — NS		1 47.7?	1 48.6	1 49.4	2 1.6	0.4	
		W — EW						0.2	
		W — NS						0.1	
246	Nov. 8	B — EW						0.5	
		B — NS		6 3.5?		6 6.0	6 13	0.3	
		W — EW						0.2	
247	Nov. 14	B — EW			About	10 0		0.2	
248	Nov. 16	B — EW	3 39.4	3 49.2	4 8.3	4 23.0	6 19	1.5	0.6
		B — NS		3 49.3	4 8.0	4 29.0	6 12	0.7	
		W — EW	3 39.2	3 48.6	4 9.2	4 22.4	5 50	0.4	
249	Dec. 21	B — EW		18 9.5	18 { 17.7, 19.3 }	18 27.8	19 10	9.0	5.0
		B — NS	18 2.8	18 9.5	18 { 17.4, 19.1 }	18 22.0	19 11	6.9	
		W — EW	18 2.9	18 9.4	18 { 17.3, 19.1 }	18 22.3	19 43	0.9	
		W — NS			18 19.0	18 21.6		0.1	
250	Dec. 21	B — EW			21 15.5	21 22.0	21 49.3	0.9	
		B — NS			21 15.0	21 21.5	21 45.5	0.2	
		W — EW			21 14.9	21 25.0	21 41.5	0.1	
251	Dec. 28	B — EW		21 29.4	21 { 38.2, 42.8 }	21 48.0	22 21.0	5.0	
		B — NS		21 29.0	21 { 38.4, 44.2 }	21 49.8	21 50	3.0	
		W — EW			21 37.4	21 47.8		0.5	
252	Dec. 29	B — EW	22 59.9?	23 1.7		23 15.5	24 22	6.5	
		B — NS	22 56.6	23 1.3	23 6.6?	23 16.9	23 58	7.0	
		W — EW	22 56.7	23 1.5		23 12.2	24 13	1.1	
		W — NS	22 56.6			23 20.2		0.2	
	1918								
253	Jan. 4	B — EW	4 36.2	4 42.5	4 44.7?	4 49.0	5 31	0.6	
		B — NS		4 43.7?		4 50.0		0.1	
		W — EW	4 36.9	4 43.2	4 44.9	4 49.0		0.2	
		W — NS	4 36.0	4 42.6	4 48.9?	4 50.0	5 11	0.1	
254	Jan. 25	B — EW	1 26.7	1 33.3	1 36.8	1 41.9	2 10	0.5	
		B — NS	1 25.8	1 32.7	1 36.4	1 39.0		0.5	
		W — EW	1 26.8	1 33.4	1 36.8	1 37.0	2 15	0.2	
		W — NS	1 26.8	1 33.4	1 37.0	1 40.0		0.1	
255	Jan. 30	B — EW	21 31.0	21 40.4	21 58.4	21 59.0	22 25	0.6	8.7
		B — NS	21 30.5	21 40.3	21 55.9	22 0.1	22 33	0.2	
		W — EW	21 31.0	21 40.5	21 57.7	21 59.0	22 25	0.2	
		W — NS	21 30.6	21 40.5	21 57.0	21 58.0	22 35	0.1	

NO.	DATE	INST. COMP.	P	S	I	M	F	A	Δ
	1918		h m	h m	h m	h m	h m	mm.	mgm.
256	Feb. 3	B — EW			14 56	15 8		0.1	
		W — EW			14 56		15 24	0.1	
		W — NS			15 0?		15 23		
257	Feb. 4	B — NS		20 51?	20 54				
258	Feb. 12	B — EW	1 38.2?		1 38.9	1 39.3	1 46.1	0.2	
		B — NS	1 38.1?		1 38.9	1 39.0	1 45.0	0.3	
		W — NS	1 38.3?		1 38.8	1 39.2	1 45.0	0.2	
259	Feb. 12	B — EW	19 31.4		19 31.9	19 32.4	19 55	0.1	
		B — NS	19 31.4		19 31.8	19 32.2		0.2	
		W — NS	19 31.3		19 31.9	19 32.2			
260	Feb. 12	W — NS			19 43.3	19 44.5	19 54		
261	Feb. 12	B — EW	20 15.6†	20 17.7	20 18.2	20 18.9	20 35	0.3	
		B — NS		20 17.5	20 18.1	20 18.5	20 30	0.5	
		W — EW		20 17.6	20 18.3	20 18.5	20 32	0.1	
		W — NS		20 17.6	20 18.3	20 18.5	20 35	0.1	
262	Feb. 13	B — EW	6 23?	6 32.2	6 59.1	7 5.0		0.5	12+
		B — NS	6 22.2	6 31.6*	7 0.5	7 10.0	8 30		
		W — EW	6 22.5	6 32.3	6 59.0	7 5.0		0.5	
		W — NS		6 35.9	7 0.1	7 10.2	8 32	0.5	
263	Feb. 24	B — EW			23 9	23 18.6	23 34	0.2	
264	Mar. 16	W — EW	13 55.4*	13 56.2	13 57.4			0.5	
		W — NS	13 55.4		13 57.4			0.5	
		B — EW	13 55.4	13 56.2	13 57.4			1.0	
		B — NS	13 55.5		13 57.5			0.5	
265	Mar. 19	W — EW			0 50		1 26		
266	Mar. 21	W — NS	17 5.7?		17 21.5	17 21.5	17 35		
		B — EW	17 5.0?		17 20.0	17 20.0	17 37		
		B — NS	17 6.0?			17 20.0	17 39		
267	Apr. 10	W — NS			1 11.6		1 13	0.5	
		B — NS			1 11.6		1 13	0.5	
268	Apr. 10	W — NS			2 15				
269	Apr. 15	B — EW	8 36.2		8 50.0	8 51.0	9 11	0.5	5.0
		B — NS	8 36.1		8 50.7	8 52.6		0.4	
		W — EW	8 36.2		8 50.2	8 51.2		0.2	
		W — NS	8 36.2	8 42.7	8 49.6	8 51.0		0.6	
270	Apr. 17	W — NS	6 56?		7 1.2	7 3.0	7 20	0.2	
		B — EW			7 1.5	7 3.0	7 3	0.2	

NO.	DATE	INST. COMP.	P	S	L	M	F	A	Δ
	1918	h m	h m	h m	h m	h m	h m	mm.	mgm.
271	Apr. 21	W — EW	22 38.3	22 43.2	22 47.0	22 50			3.0
		W — NS	22 38.4	22 43.1	22 46.8	22 47.1			
		B — EW	22 38.3	22 43.0	22 47.2	22 49.4			
		B — NS	22 38.4	22 43.2	22 46.4	22 47.2			
272	Apr. 27	B — NS			15 1.5	15 5.0		0.2	4.2
		W — NS	14 51+	14 56.8	15 1.6	15 4.0		0.3	
273	May 6	W — EW		5 10.4	15 12.4	15 11.6		0.3	
		W — NS		5 10.3	15 12.1	15 11.6		0.6	
		B — EW		5 10.4	15 12.3	15 11.4		0.4	
		B — NS		5 10.4	15 12.1	15 11.4			
274	May 16	B — EW				21 44.1		0.5	
		B — NS	21 32.3	21 36.0		21 42.2		0.2	
		W — EW	21 32.2		21 41.8	21 42.0		0.2	
		W — NS	21 32.2	21 35.2?	21 41.5	21 42.4		0.6	
275	May 20	B — EW	14 45.3	14 53.1	15 1.6	15 5.6	17 0	6.0	5.8
		B — NS	14 45.7	14 45.7	15 1.0	15 3.4	16 45	2.0	
		W — EW	14 45.6	14 53.4	15 1.8	15 5.9	17 0	0.8	
		W — NS			15 1.6	15 3.0		1.1	
276	May 20	B — NS	18 6.8	18 16.0					
		W — NS	18 6.4		18 27.9	18 29.0	19 30	0.2	7.8
		W — EW	18 6.5		18 28.7	18 33.8	19 30	0.3	
277	May 22	B — NS		6 56.6	7 5.0	7 5.0		0.1	3.2
278	May 23	B — EW	12 3.8	12 8.6	12 11.8	12 14.4	13 38	25.0	3.3
		B — NS	12 3.9	12 8.7	12 11.5	12 13.5	13 40	71.5	
		W — EW	12 3.8	12 8.2	12 11.9	12 13.2	13 46	3.6	
		W — NS	12 3.9	12 8.7	12 11.7	12 14.4		24.8	
279	May 25	W — EW		19 50.2	20 3.0	20 4.0		0.1	8 ±
		B — EW	19 42.1	19 50.8	20 3.7	20 4.3	20 33	0.5	
		B — NS	19 41.4	19 50.9	20 4.3	20 6.7		0.2	
280	June 3	B — NS	0 24.3		0 29.2		0 45	0.1	
281	June 4	B — NS	17 40		18 5				
282	June 7	B — EW	21 33.2	21 39.6	21 45.1	21 46.3	22 43	4.2	4.5
		B — NS	21 33.1	21 39.3	21 44.7	21 45.3	22 35	2.2	
283	June 11	B — EW	12 42.5	12 46.0	12 51.5	12 57.3	13 11	0.4	4.2
		W — EW	12 42.1		12 52.0	12 57.3	13 17	0.2	
		W — NS	12 41.3	12 47.0	12 52.5	12 57.2	13 20	0.2	
284	June 12	B — EW	4 31.0	4 36.2	4 44.2	4 45.1	5 0	0.2	

NO.	DATE	INST. COMP.	P	S	I	M	F	A	Δ
	1918		h m	h m	h m	h m	h m	mm.	mgm.
285	June 13	B — EW	9 4.2	9 8.9		9 11.5	10 30	0.5	3.0
		W — EW		9 8.5	9 11.6	9 11.7	10 21	0.2	
		W — NS	9 4.5	9 9.1	9 11.6	9 11.7		0.1	
286	June 16	B — NS	12 33.5	12 38.2		12 42.0	13 4	0.4	3.0
		W — EW		12 38.3		12 42.0			
		W — NS	12 33.6	12 38.3		12 42.1	13 4	0.1	
287	June 17	B — NS	16 43.2		16 45.5				
288	June 22	W — NS	22 12.1	22 16.2		22 26	22 49	0.2	
289	July 2	B — EW	11 24		11 30				
290	July 3	B — EW	7 10.5	7 22.7	< 7 52.0	7 56	9 34	0.6	12 ±
		B — NS	7 11.2	7 21.?	7 50.0		9 25	0.2	
		W — EW	7 11.1		7 50.9				
291	July 8	B — EW			11 11	11 23	12 16	1.0	
		B — NS	10 40.4	10 51.1		11 22	12 10	1.1	
		W — EW	10 40.1		11 11	11 24	12 7	0.3	
		W — NS	10 40.0	10 52.5		11 23.6	12 7	0.2	
292	July 15	W — EW	0 29.4		0 39.7	0 43.2	1 29	0.9	4.4?
		W — NS	0 29.4		0 39.5	0 42.0	1 47	4.1	
		B — EW	0 29.1		0 40.8	0 43.0	1 42	4.9	
		B — NS	0 29.3	c 36.0	0 40.0	0 41.6	1 50	19.0	
293	July 21	B — EW	6 30.4	6 49.7	7 8.7	7 14	8 29	0.5	10.2
		B — NS	6 39.7		7 10	7 18		0.2	
		W — EW	6 39.5		7 9	7 4	8 10	0.2	
		W — NS	6 39.4		7 11				
294	July 31	B — EW	14 43.4	14 48.2	14 53.9	14 55.4	15 26	0.6	4.6
		B — NS		14 48.0	14 55.4	14 56.3	15 15	0.4	
		W — EW		14 48.3	14 54.0	14 54.4	15 25	0.2	
		W — NS	14 42.6	14 48.9	14 55.1	14 55.6	15 12	0.1	
295	Aug. 8	B — EW	10 18.3		10 38.1	10 53	11 22		
296	Aug. 15	W — EW	12 38.8		12 56.6	13 14	15 16	0.6	
		W — NS	12 37.9	12 46.1	12 56.0	13 14	15 0	0.6	
		B — EW	12 38.8		12 58.1	13 0	14 56	2.7	
		B — NS	12 38.6	12 46.6	12 56.1	12 57.3	14 55	3.1	
297	Aug. 17	B — EW		7 12.4					
		W — NS		7 12.4					
298	Aug. 23	W — EW			9 58.7				
		B — NS			10 ±				
299	Sept. 4	B — EW			20 10 ±				

NO.	DATE	INST. COMP.	P	S	L	M	F	A	Δ
	1918		h m	h m	h m	h m	h m	mm.	mgm.
300	Sept. 7	B — EW	17 28.4			18 3	22 0	15.0	6.9
		B — NS	17 28.0		17 48	18 3	23 26	16.5	
		W — EW	17 28.6		17 48	18 3	23 12	2.3	
		W — NS	17 28.9		17 49	18 3	21 30	1.6	
301	Sept. 11	B — EW			< 4 4				
		B — NS			4 2.4				
		W — EW			4 3.5				
		W — NS			4 3.7				
302	Sept. 14	B — EW		17 26.3	17 45.0		18 10	0.1	9. ±
		B — NS	17 15.5						
		W — EW	17 15.5						
303	Sept. 29	B — EW	12 19.3	12 29		12 30		0.2	
		B — NS	12 19.7			12 30		0.1	
		W — EW	12 19.5			12 29.9			
		W — NS	12 19.7	12 29.0	12 42?			0.1	
304	Oct. 11	B — EW	14 20.4	14 25.1					
		B — NS	14 20.3	14 25.0	14 28 ±				3.0
		W — EW	14 20.4	14 25.0	14 28.7	14 35.0		7.0	
		W — NS	14 20.3	14 25.0	14 28.7	14 35.5		9.7	
305	Oct. 11	B — EW	17 9.6			17 23		0.6	
		B — NS	17 9.4			17 23		0.3	
		W — EW	17 9.5		17 17.0	17 24		0.3	
		W — NS	17 9.5		17 18.0	17 23		0.4	
306	Oct. 18	B — EW				21 54		0.1	4.2?
		B — NS				21 54			
		W — EW	21 37	21 43.7	21 48.4	21 54	22 15	0.1	
		W — NS	21 37.2	21 43.0	21 48.2	21 54	22 16		
307	Oct. 19	W — EW	3 29.1	3 33.8	3 38.6	3 42.3	4 20	0.4	3.0
		W — NS	3 29.0	3 33.8		3 42.0	4 30	0.3	
		B — EW	3 30 ±	3 33.6		3 40.0	4 15	1.6	
		B — NS	3 29.3	3 33.9		3 40.0	5 20	1.1	
308	Oct. 25	B — EW	3 48.5	3 53.3	3 55.7	4 3.0	5 0	0.5	3.0
		B — NS	3 48.7	3 53.4	3 56.0	4 4.0	5 2	0.3	
309	Oct. 27	B — EW		15 54.6	16 24 ±				
		B — NS		15 54					
310	Oct. 27	B — EW		17 27.1?	18 1.0	18 12		0.4	
		B — NS		17 27.0?	18 0.5	18 13		0.2	
		W — EW	17 16.9		18 2.0	18 12	19 30	0.2	
		W — NS		17 27.2?	18 1.0	18 15	19 25	0.2	
311	Oct. 29	B — EW		11 32	11 45	12 50		0.3	
		B — NS		11 31	11 45	12 50		0.2	

NO.	DATE	INST. COMP.	P	S	I	M	F	A	Δ
	1918		h m	h m	h m	h m	h m	mm.	mgm.
312	Nov. 2	B — EW		10 27.5	10 35.6	10 37		0.2	
		B — NS		10 25.0	10 35.1	10 37		0.2	
313	Nov. 3	B EW			12 20	12 26		0.3	
314	Nov. 8	B — EW	4 49.3	4 59.0	5 15.8	5 21.3	7 50	9.0	8.7?
		B — NS	4 49.2	4 59.0	5 15.0	5 29.5	8 0	6.8	
315	Nov. 12	B — EW	21 50.9	21 55.3	21 57.7	22 3.0		1.2	2.9
		B — NS	21 51.0	21 55.3	21 57.6			0.6	
316	Nov. 18	B — EW		19 0.8	19 40.0	19 46		1.1	
		B — NS		19 0.9		19 52	22 ±	0.8	
317	Nov. 30	B EW		7 16		7 31		0.4	
		B — NS		7 16		7 32		0.2	
318	Dec. 2	B — EW	9 50.0	10 2.9	10 9.8	10 11.2	11 15	0.6	5.2
		B — NS		10 2.8	10 10.0	10 11.0		0.3	
		W — EW	9 55.0	10 2.8	10 9.8	10 11.0	11 15	0.4	
		W — NS	9 56.0	10 2.8	10 10.0	10 10.5		0.2	
319	Dec. 4	B — EW	11 58.5	12 7.3	12 18.6	12 20.0		3.5	7.8
		B — NS	11 58.4	12 7.8	12 18.4	12 28.0		4.0	
		W — EW	11 58.6	12 7.3	12 18.7	12 20.0		1.1	
		W — NS	11 58.5	12 7.8	12 19.0	12 28.0		2.0	
320	Dec. 6	B — EW	8 46.5	8 51.6	8 53.0	8 57.7	10 0	16.5	3.0
		B — NS	8 46.4	8 51.5	8 53.6	8 57.4	9 50	25.4	
321	Dec. 6	B — EW		12 15		12 19	12 35	0.4	
		B — NS			12 18.5	12 19	12 40	0.6	
322	Dec. 9	B — EW		18 32.6	18 37.0	18 41		0.2	
		B — NS		18 32.5	18 36.0	18 40		0.1	
		W — EW		18 32.3	18 35.4	18 40.5		0.1	
323	Dec. 9	B — EW			19 24	19 28	20 20	0.5	
		B — NS			19 23	19 31		0.3	
		W — EW			19 22	19 27	20 15	0.2	
		W — NS			19 23	19 30		0.2	
324	Dec. 21		9 33	(See	Remarks)				4.8?
325	Dec. 23	B — EW		19 55.2	19 59	20 5	20 30	0.5	
	1919								
326	Jan. 1	B — EW	1 53.9?		2 20				
		B — NS	1 54.5?						
327	Jan. 1	B — EW	3 18.0?	3 23.5	3 26.0	3 27.0	6 5		3.0 ±
		B — NS	3 17.7	3 22.2?	3 26.2		6 ±	22.5	
328	Jan. 8	B — EW				2 6	2 15	0.1	

NO.	DATE	INST. COMP.	P	S	L	M	F	A	Δ
	1919		h m	h m	h m	h m	h m	mm.	mgm.
329	Jan. 17	B — EW	11 56.?	12 0.4		12 0.5	micros	0.5	3.4?
		B — NS	11 55.6	12 0.5		12 0.7		0.2	
		W — EW	11 55.4	12 0.5		12 0.7		0.1	
		W — NS	11 55.5	12 0.5		12 1.0		0.1	
330	Jan. 27	W — EW			22 12				
331	Jan. 31	B — EW	23 59.5?		0 2.3	0 3.2	0 22	0.5	
		B — NS	23 59.3?		0 2.1	0 2.5		0.5	
332	Mar. 2	B — EW	3 41.2?	3 49.8	4 3.2?				
		B — NS		3 49.9					
		W — EW		3 49.8	4 6.3				
333	Mar. 2	B — EW		12 8.2	12 21.0	12 23.4		0.4	8 ±
		B — NS	11 58.5?	12 8.5	12 20.3	12 23		0.5	
		W — EW		12 8.2	12 20.7	12 23.2		0.2	
334	Mar. 9	B — EW		3 42.6	4 3.5	4 9.		0.2	
		B — NS		3 42.8	4 3.9	4 9.		0.1	
335	Apr. 17	B — EW		11 51.4	12 4.0	12 33	14 10	0.6	8.5?
		W — EW	11 41.7?	11 51.5	12 5.1	12 33	14 15	0.2	
336	Apr. 17	B — EW	20 59.0	21 4.2		21 12.7	22 20	15.5	3.0
		W — NS	20 58.8	21 4.1	21 10.5?	21 12.6	22 10	2.6	
337	Apr. 18	B — EW		21 12.1	21 17.6	21 18.0	22 20	2.0	3.5
		W — EW		21 12.4	21 17.5	21 18.0	22 30	1.0	
		W — NS		21 12.3	21 17.4	21 18	22 20	1.2	
338	Apr. 21	B — EW			11 00				
339	Apr. 28	B — EW	6 54.7?	7 0.4?	7 2.4	7 2.7		0.6	3.1
		B — NS		6 59.2?	7 2.4	7 6.0	7 55.0	0.5	
		W — EW		6 59.0	7 2.3	7 3	8 20	0.5	
		W — NS		6 59.4	7 2.7	7 5.9	8 10		
340	Apr. 30	B — EW	7 30.2?		8 0.4	8 27	12 0	21.0	12.0
		B — NS		7 42.8	8 0	8 22	12 0	16	
		W — EW	7 31?		7 59.8	8 27	12 0	4.8	
		W — NS		7 42.9	7 59	8 26	11 45	3.1	
341	May 2	B — EW	2 31?		2 49	3 3	4 20	0.8	
		W — EW	2 33?		2 50	3 3	4 30	0.5	
342	May 3	B — EW	1 4.7	1 15.4	1 32.3	1 38.1	3 50	1.4	9.4
		W — EW	1 4.7	1 15.2	1 32.0	1 38	4 0	0.6	
		W — NS	1 4.7	1 15.1	1 32.0	1 42	3 30	0.7	

NO.	DATE	INST. COMP.	P	S	L	M	F	A	Δ
	1919		h m	h m	h m	h m	h m	mm.	mgm.
343	May 6	B EW	20 1.3	20 11.2	20 31.7	20 45	23 0	3.5	9.8
		B NS	20 1.1?		20 32.0	20 46	23 10	1.8	
		W EW	20 1.4		20 31.8	20 45	23 10		
		W NS	20 1.5		20 32.0				
344	May 7	B EW	5 39?	5 45.6	6 10.	6 22		0.4	
345	May 18	B EW	10 42.2						2.5
		B NS	10 42.4	10 44.8	10 48.4				
346	May 20	B EW			4 37.3	4 38		0.2	
347	May 22	B EW			12 30				
348	June 29	B EW	23 20.4	23 25.3	23 28	23 29	0 15	1.3	3.1
		B NS	23 20.7	23 25.6	23 28.5	23 30	0 30	1.4	
		W EW	23 20.5	23 25.3		23 30	0 20	0.5	
		W NS	23 20.7	23 25.4	23 29.3	23 30		0.7	
349	July 6	B EW		7 15.7		7 21	8 0	0.5	3.5
		B NS				7 20		0.3	
		W EW		7 15.5					
		W NS	7 10.7	7 15.9	7 19.3	7 21	8 0		
350	July 8	B EW		21 31.4		22 11	23 10	1.2	
		B NS	21 24.6?		21 53	22 14		0.6	
		W EW			21 51	22 10	23 30	0.5	
351	July 9	B EW	19 32.2	19 35.3?		19 38.8	20±	0.6	
		B NS		19 35.9?		19 38.9		0.5	
		W EW			19 37.2?	19 38.5	20 15±	0.2	
352	July 17	B EW	16 25.9		16 57			0.5	3.7
		B NS	16 26.1	16 31.4	16 37.5	16 41.2		0.5	
		W EW			16 37.1?				
		W NS	16 27.1?						
353	July 22	B EW		22 12.2	22 14.5	22 14.9	22 35	0.7	2.9
		B NS	22 7.3	22 12.2					
		W EW	22 7.5	22 12.2	22 14.5	22 15.0			
		W NS	22 7.5	22 12.2		22 15.7			
354	Aug. 18	B NS	17 20.5?		17 40				
		W NS	17 20.7?						
355	Aug. 31	B EW	17 38.5	17 51	Uncertain	18 30	19 30	1.5	
		B NS			18 2				
		W EW	17 38.8	17 51.5		18 32		0.5	
		W NS			18 12				
356	Sept. 6	B NS	9 30.1	9 37.1	< 9 43	9 40	10 30	0.4	5.3
		W EW			9 42.8	9 48.8		0.2	
		W NS			9 42.8	9 48.8	10 20		

NO.	DATE	INST. COMP.	P	S	L	M	F	A	Δ
	1919		h m	h m	h m	h m	h m	mm.	mgm.
357	Sept. 13	B — EW			12 50±				
		B — NS			12 50±				
358	Sept. 15	B — EW			17 26±				
359	Sept. 27	B — EW			4 00±				
360	Oct. 3	B — EW				10 40	11 0	0.3	
361	Oct. 10	B — EW		1 19.7	1 25.3	1 27.0		0.5	
		B — NS			1 25.3	1 27.2		0.3	
		W — EW		1 19.8	1 25.4	1 27.0		0.2	
		W — NS			1 25.5	1 26.5		0.2	
362	Oct. 12	B — EW			23 0				
363	Oct. 27	B — EW			4 0				
364	Nov. 6	B — EW	lacking						
		B — NS	7 15.8		7 27±	7 28.6	7 50		
365	Nov. 18	B — EW			22 30+				
366	Nov. 20	B — EW			15 0+				
367	Dec. 5	B — NS		0 28.6	0 33.3		0 49		
		W — EW		0 28	0 33.5	0 35			
368	Dec. 14	B — EW			2 16				
	1920								
369	Jan. 4	B — EW	4 27.5	4 32.2	4 35.5	4 40.5	5 20	0.75	3.0
		B — NS	4 27.7	4 32.1		4 40.0	5 20	0.50	
		W — NS	4 27.7	4 32.5				0.25	
370	Jan. 30	B — EW	18 35.6	18 41.8	18 44.9		19 02.3		3.4
		B — NS	18 35.7	18 41.6	18 44.7				
371	Feb. 2	B — EW	11 41.2		12 31.7	12 36.5	14 14.0	1.50	13.0
		B — NS	11 41.4		12 31.9	12 36.5	14 13.0	1.10	
		W — EW			12 31.8				
		W — NS			12 31.8				
372	Feb. 7	B — EW			12 9.1	12 9.7			
		B — NS			12 9.2	12 10.0			
		W — EW			12 9.2				
373	Feb. 10	B — EW	22 13.0	22 17.1	22 19.5	22 28.3	23 39.0	0.65	2.7
		B — NS	22 13.1	22 17.3	22 19.4	22 28.1	23 35.0	0.15	
		W — EW	22 13.0	22 17.2	22 19.0				
		W — NS	22 13.0	22 17.2	22 19.1	22 28.4			

NO.	DATE	INST. COMP.	P	S	L	M	F	A	Δ
	1920		h m	h m	h m	h m	h m	mm.	mgm.
374	Feb. 12	B — EW			0 44.5				
		B — NS			0 44.5				
		W — NS		0 40.0	0 44.6				
375	Mar. 20	B — EW	18 40.1	18 55.2	19 8.8	19 13.7		0.50	7.7
		B — NS	18 40.2	18 55.6	19 8.6	19 9.6	20 40.0	0.70	
		W — EW			19 8.8				
		W — NS		18 55.2	19 8.8	19 9.7		0.25	
376	Mar. 23	B — EW		15 33.5	15 37.9				3.9
		B — NS	15 28.0	15 33.1	15 37.9	15 43.7	16 13.0	0.25	
		W — EW	15 27.9	15 33.0	15 37.9				
		W — NS	15 27.9	15 33.1	15 37.9				
377	Mar. 29	B — NS	5 14.8	5 20.2	5 24.7	5 28.9	0 39.0	9.00	3.9
		W — EW		5 20.1		5 28.0		1.00	
		W — NS		5 20.1	5 24.8	5 28.0		1.50	
378	Apr. 18	B — EW			21 28.8				
		B — NS			21 20.0				
379	Apr. 19	B — EW	21 12.4	21 16.5	21 18.6		21 47.0		2.8
		W — EW	21 12.0	21 16.7	21 18.6				
		W — NS	21 12.4	21 16.6					
380	May —	B — EW			22 28.2	22 40.1	23 52.0	1.00	
		B — NS			22 28.2				
		W — EW			22 28.4				
		W — NS			22 27.7	22 40.9			
381	May 31	B — EW	2 0.9	2 20.7	2 50.9		3 4.0		12.6
		B — NS	2 0.4	2 20.3	2 50.8				
		W — EW	2 10.0	2 21.4					
382	May 20	B — EW			8 20.8				
		B — NS			8 21.3				
		W — NS			8 20.6				
383	May 30	B — EW			21 3.3				
		B — NS			21 3.3				
384	June 2	B — EW	22 17.1	22 21.9	22 25.1	22 17.7	23 0.0	0.75	3.3
		B — NS	22 16.9	22 21.8	22 24.8	22 17.5		0.75	
		W — EW	22 17.1	22 21.1					
		W — NS	22 16.4	22 21.7	22 24.1				
385	June 4	B — EW	15 40.4	15 47.3	15 50.7		16 48.0		5.4
		B — NS	15 40.3	15 47.1	15 50.7		16 52.0		
		W — NS	15 40.0		15 50.7				

NO.	DATE	INST. COMP.	P	S	L	M	F	A	Δ
	1920		h m	h m	h m	h m	h m	mm.	mgm.
[illegible]6	June 5	B — EW	4 39.4	4 49.8	5 20.1	5 { 21.5 / 33.1	6 31.0	1.25 / 1.00	13
		B — NS	4 39.7	4 49.6	5 21.6	5 { 28.7 / 33.7	6 33.0	1.00 / 1.50	
		W — EW			5 21.3				
		W — NS			5 21.3				
387	June 18	B — EW	10 25.0						
388	June 22	B — EW	22 3.2						
389	July 2	B — EW	19 37.6				20 0.0		
390	July 7	B — EW	18 48.3	18 54.8	19 1.9	19 1.[illegible]	19 39.0	3.50	5.0
		B — NS						2.50	
		W — EW			19 1.9	19 2.[illegible]		1.50	
		W — NS				19 5.0		0.50	
391	July 10	B — EW	17 23.8	17 28.3	17 22.3		18 53.0		2.8?
		B — NS			17 22.6				
3[illegible]	July 20	B — EW	5 21.0	5 28.4	5 38.6				
		W — NS	5 20.6		5 38.2				
[illegible]	Aug. 3	B — EW	20 7.0	20 17.8	20 30.2	20 38.7	20 30.0	0.50	8.0
		B — NS	20 7.2	20 17.9	20 29.8	20 38.2	20 28.0	0.50	
3[illegible]	Aug. 15	B — EW	8 34.4	8 44.7	9 7.2		.		10.6
		B — NS		8 44.6	9 7.1				
3[illegible]5	Aug. 20	B — EW	23 8.5	23 17.0	23 28.8		0 11.0		7.1
396	Sept. 5						16 45		
397	Sept. 8	B — EW	2 4.3	2 11.0	2 31.1				10.5
		B — NS		2 10.7	2 30.9				
398	Sept. 9	B — EW	19 13.9		19 43.7		21 15.0		
		B — NS			19 43.7		21 15		
399	Sept. 21	B — EW	18 4.1						
		B — NS	18 3.9						
400	Sept. 24	B — EW	17 0.6						
		B — NS	17 0.7						
401	Sept. 27	B — EW	5 38.7						
		B — NS	5 38.8						
		W — EW	5 38.6						
402	Oct. 1	B — EW			19 0.8				
		B — NS			19 0.8				

NO.	DATE	INST. COMP	P	S	L	M	F	A	Δ
	1920		h m	h m	h m	h m	h m	mm.	mgm.
403	Oct. 5	B — EW			19 20.6				
		B — NS			19 20.4				
404	Oct. 7	B — EW	21 4.0	21 11.6	21 19.4	21 22.2	21 56		5.6
		B — NS		21 11.8	21 19.7		21 58		
405	Oct. 8	B — EW	16 56.9	17 1.7	17 5.9	17 8.2	18 0.0	0.50	3.5
		B — NS		17 1.8	17 6.1	17 8.8	18 0.0	0.50	
		W — EW			17 5.7				
		W — NS	16 57.1						
406	Oct. 18	B — NS	8 23.5	8 33.4	8 57.5		9 50		11.2
407	Oct. 25	B — EW	12 20.4	12 28.9	12 36.5				5.7
		B — NS	12 20.5	12 29.1	12 36.5				
		W — EW			12 36.5				
		W — NS	12 20.5	12 29.2					
408	Oct. 28	B — EW			7 56.7				
		B — NS			7 56.7				
409	Oct. 28	B — EW	13 1.4	13 10.5	13 25.8				8.4
		B — NS	13 1.1	13 10.6	13 26.2				
		W — NS		13 10.4	13 26.8				
410	Nov. 4	B — EW	2 22.3						
		B — NS	2 22.5						
411	Nov. 6	B — EW			10 54.3				
		B — NS			10 54.3				
412	Nov. 12	B — EW			6 12.9				
		B — NS			6 12.8				
413	Nov. 16	B — EW	8 38.2	8 44.1	8 50.1	8 51.2	9 36.0	5.00	4.3
		B — NS	8 38.2		8 50.4		9 36.0		
		W — NS	8 38.2	8 44.5	8 50.4				
414	Nov. 29	W — EW	8 12.0						
		W — NS			8 25.4				
415	Dec. 10	B — EW		4 47.5	5 2.3		6 0		8.3
		B — NS	4 37.5	4 47.4	5 2.2		6 0		
416	Dec. 11	B — EW	21 28.1	21 34.0	21 38.0				3.7
		B — NS	21 28.5	21 33.6	21 38.2				
417	Dec. 16	B — EW	12 20.0	12 30.2	12 51.4	13 7.9	15 0	28.00	10.3
		B — NS	12 19.0	12 30.3	12 51.8	13 7.9	15 0	43.00	
418	Dec. 17	B — EW	19 10.0	19 23.0	19 38.1				8.4
		B — NS	19 10.2	19 22.2	19 38.4				

NO.	DATE	INST. COMP.	P	S	L	M	F	A	Δ
	1920		h m	h m	h m	h m	h m	mm.	mgm.
419	Dec. 25	B EW			12 28.7		13 0		
		B — NS			12 28.7		13 0		
	1921								
420	Jan. 2	B — EW	7 32.1						
		B — NS	7 32.5						
421	Jan. 8	B — EW	6 42.8	6 47.1	6 51.8	6 53.1			3.7
		B — BS	6 42.6	6 47.1	6 51.6				
		W — NS	6 42.6						
422	Jan. 9	B — EW		13 12.2	13 22.8				6.5
		B — NS		13 12.1					
423	Jan. 20	B — EW	21 9.6	21 15.0	21 19.3				
		B — NS	21 9.4						
424	Feb. 4	B EW	8 28.8	8 33.8	8 36.4	8 40.8	9 39		3.2
		B — NS	8 28.7	8 33.6	8 36.4	8 45.0	9 39		
		W — NS	8 28.8	8 33.7	8 36.4				
425	Feb. 6	B — EW			5 22.1				
		W — EW			5 22.0				
426	Feb. 11	B — EW			0 48.0				
		B — NS			0 48.1				
427	Feb. 11	B — EW			22 57.3				
		B — NS			22 57.8				
428	Feb. 14	B — EW			1 48.8				
		B — NS			1 48.6				
429	Feb. 19	B — EW			15 55.7				
		B — NS			15 55.5				
430	Feb. 19	B — EW			18 51.0				
		B — NS			18 51.9				
431	Feb. 21	B — EW			12 0.1				
		B — NS			11 59.9				
		W — EW			12 0.0				
432	Feb. 21	B — EW	16 6.7		16 14.3	16 16.8			3.0
		B — NS	16 7.0		16 14.2	16 17.3			
		W — EW	16 6.8	16 11.7	16 14.5	16 16.7			
		W — NS			16 14.5				
433	Feb. 21	B — EW				19 44.5			
		B — NS				19 44.2			
		W — EW				19 44.2			
434	Feb. 27								

NO.	DATE	INST COMP.	P	S	I	M	F	A	Δ
	1921		h m	h m	h m	h m	h m	mm.	mgm
435	Mar. 6	B — EW		7 35.7	7 39.9	7 41.5		5.00	3.5
		B — NS		7 35.7	7 39.9	7 41.3		14.00	
		W — EW			7 39.9				
		W — NS		7 35.6	7 39.5	7 41.7			
436	Mar. 12	B — EW		10 44.3	10 50.2				4.6
		B — NS		10 44.5	10 50.3				
		W — NS			10 50.0				
437	Mar. 16	B — EW			12 34.7				
		B — NS			12 35.0				
438	Mar. 21	B — EW			4 24.9				
		B — NS			4 24.4				
439	Mar. 24	B — EW			9 45.3				
		B — NS			9 45.2				
440	Mar. 24	B — EW			10 26.1				
		B — NS			10 26.0				
441	Mar. 24	B — EW		15 2.8	15 19.1				8.6
		B — NS		15 3.0	15 19.6				
442	Mar. 25	B — EW			0 40.5				
		B — NS			0 40.5				
443	Mar. 28	B — EW	7 55.5	8 0.5	8 2.7	8 3.6		11.5	3.1
		W — EW			8 3.2	8 3.5		2.5	
		W — NS			8 2.8				
444	Mar. 29	B — EW			22 49.1				
		B — NS			22 49.4				
445	Apr. 1	B — EW			5 17.9				
		W — EW			5 17.9				
446	Apr. 1	B — EW			12 58.7				
		B — NS			12 58.4				
		W — EW			12 58.9				
		W — NS			12 58.9				
447	Apr. 2	B — EW			10 5.2				
		B — NS			10 5.3				
448	Apr. 5	B — EW			0 37.6				
		B — NS			0 37.5				
449	Apr. 10	B — EW			14 0.0	14 2.0		2	4.3
		B — NS	13 48.8	13 55.1	14 0.1	14 1.3		1	
		W — EW			14 0.0				

NO.	DATE	INST. COMP.	P	S	L	M	F	A	Δ
	1921		h m	h m	h m	h m	h m	mm.	mgm.
450	Apr. 12	B — EW			7 52.6				
		B — NS			7 52.1				
		W — EW			7 52.6				
451	Apr. 20	B — EW			19 5.9				
		B — NS			19 5.0				
452	Apr. 25	B — EW			18 47.1				
		B — NS			18 46.8				
		W — EW			18 46.8				
453	May 1	B — EW	5 45.4	5 50.8	5 57.0	5 57.9	7 20	13.00	4.4
		B — NS	5 45.0		5 56.9	5 57.9	7 20	5.00	
		W — EW	5 45.2		5 57.4				
		W — NS	5 44.8		5 56.9				
454	May 14	B — EW			21 20.6				
		B — NS			21 20.5				
455	May 14	B — EW			22 25.3				
		B — NS			22 25.1				
456	May 20	B — EW			1 26.8				
		B — NS			1 28.0				
457	May 21	N — EW			9 1.5				
		B — NS			9 1.7				
458	May 28	B — EW			22 12.9				
		B — NS			22 12.8				
459	June 4	B — EW			1 42.8				
		B — NS			1 42.6				
460	July 25	B — NS			19 31.2				
		W — EW			19 34.8				
		W — NS			19 32.0				
461	July 25	B — NS			19 57.5				
		W — EW			19 57.7				
		W — NS			19 57.7				
462	Aug. 14	B — EW			14 1.7				
		W — EW			14 1.5				
463	Aug. 16	B — EW			18 20.4				
		B — NS			18 19.8				
		W — EW			18 19.9				
		W — NS			18 20.1				
464	Aug. 19	B — EW			8 39.5				
		B — NS			8 39.2				

NO.	DATE	INST. COMP.	P	S	L	M	F	A	Δ
	1921		h m	h m	h m	h m	h m	mm.	mgm
465	Aug. 21	B — EW			1 8.3				
		B — NS			1 8.5				
		W — EW			1 8.3				
		W — NS			1 8.2				
466	Aug. 23	B — EW	20 24.8	20 31.9					3.9
		B — NS			20 34.9				
467	Aug. 26	B — NS			19 7.7				
468	Sept. 5	B — EW			20 43.4				
		W — EW			20 48.1				
		W — NS			20 42.8				
469	Sept. 8	B — EW			19 40.6				
		B — NS			19 40.8				
470	Sept. 11	B — EW	4 21.3	4 35.4	5 13.4	5 24.8	7 28.0		17?
		B — NS	4 21.5	4 35.2	5 13.7	5 26.1	7 10.0		
471	Sept. 13	B — EW			2 41.9				
472	Sept. 19	B — EW			4 40.1				
		B — NS			4 40.1				
473	Sept. 20	B — EW			1 10.6		2 6.0		
		B — NS			1 10.3				
474	Oct. 15	B — EW			5 57.0		6 50.0		
		B — NS			5 57.2				
475	Oct. 20	B — EW		6 22.9					7.9
		B — NS	6 13.6	6 22.0			7 27		
		W — EW	6 13.6	6 22.9					
		W — NS	6 13.6	6 22.9					
476	Nov. 2	B — NS	3 49.3		3 56				
477	Nov. 2	B — NS	8 22			8 30			
478	Nov. 11	B — EW	*18 56.7	19 6.9	19 23?	19 44	21 15	1.0	0.0
		B — NS	18 56.8	19 7.0		19 44	21 10	0.6	
479	Nov. 13	B — EW			8 53				
		B — NS	8 49		8 53.5				
480	Nov. 15	B — EW		21 0.1		21 20	22 30	0.6	9.0
		B — NS	20 49.8	21 0.0	21 16	21 20	22 40	0.5	
481	Dec. 18	B — NS			11 30				
482	Dec. 18	B — EW	15 37.2	15 43.3		15 43.4	17 30	10.1	4.3
			15 37.1	15 43.3		15 43.4	17 40	6.0	

186. The phases marked S on the EW components are probably S R_1.)

187. A small disturbance lasting about 15 minutes.

188. A small disturbance lasting about 8 minutes.

Mar. 31. Very slight disturbance (microseismic?) about 17^h.

Apr. 2. Very slight disturbance (microseismic?) about $19^h\ 12^m$ on B — NS: trace only on B — EW.

193. No record on W — NS, pen insensitive.

194. Small record covering 10 minutes. Actual quake?

195. Some very slow waves.

Apr. 21. B — EW shows some flat waves not very regular. W — EW quite a distinct disturbance, looks like a distant quake. M at $12^h\ 16^m$.

May 9. B — NS shows a few undulations about 16^h.

205. B — NS record defective. W records not black enough to be legible.

206. Impossible to differentiate phases on B records. On W records the tremors are very faint and confused with those due to trains.

207. No record discernible on the W — NS. F on W — E lost in tremors due to trains.

208. No trace on W — NS or W — V. P on B — EW confused with train tremors.

Oct. 3. Earthquake recorded on B — NS and W — EW but time not determinable. Pen on B — EW not tracing. Clock stopped.

209. The W — EW record is marred so that the times of S and L may not be read.

210. The beginning of the B — NS record cannot be accurately read, because of other disturbances; passing trains? F on W — EW cannot be accurately read for the same reason. No motion of the pen is discernible on W — NS, except a very feeble trace of the long waves. No trace on W — V.

212. Faint trace on W — V, but not legible. P on W — EW cannot be read because the sheet was marred.

213. Beautiful record with all phases distinctly marked except on the W — NS. No record on the W — V. There are two well marked epochs of maximum amplitude on the B — EW.

214. Microseisms prevent F from being accurately read. The pen left the B — NS record at $19^h\ 43^m.5$ interrupting the trace until $19^h\ 53^m.0$. The drum of B — EW was not rotating when the disturbance started. Consequently only the last phases are recorded of this component. No trace on W — V. W — NS record incomplete. S on W — EW indistinguishable from P.

215. This is the local shock reported in the St. Louis, Mo., newspapers. The phases are not discernible, the beginning and ending being lost in the microseismic tremors. The record on the B — EW is not discernible from the microseisms.

216. The phases are very poorly defined. No record appears on the W — NS and that on the B — NS is very feeble.

217. On both components of the B instruments and on the W — EW the record is well traced out and the phases well defined. The time marker of the B — EW was not operating. No record appears on the W — NS.

218. This disturbance is a series of sinusoidal waves of very small amplitude and of 20 seconds period. There are no well marked phases.

219. Maxima occur at $17^h\ 57^m$, $18^h\ 20^m$, $19^h\ 57^m.5$, $20^h\ 24^m.0$. There is no record on the W — NS or on either of the Bosch sheets. The preliminary tremors continue irregularly until $17^h\ 20^m$ when they become more vigorous and continuous (microseisms).

220. The phases are well marked. No record on W — NS sheet.

221. This disturbance is very feeble. The phases are not distinguishable.

223. These are very feeble oscillations, less than 0.5 mm. in amplitude. No phases are indicated.

225. Pen on W — EW not working properly. B — EW stopped June 25, at $23^h\ 3^m$.

226. Beginning cannot be identified. B — EW not running.

228. Probably a slight quake. Discerned among microseisms by length of period.

229. Similar to July 4.

231-232. Probably not seismic disturbances as no records occur on the other instruments. (Faint trace afterward found on W — EW corresponding with $21^h\ 24^m.5$). The period on B — EW agrees with the period of the instrument. The damping is gradual showing no continuation of disturbance.

233. B — NS merely gave a lateral movement at the maximum, but did not oscillate.

234. W — NS had very faint waves only at the time of maximum. W — EW record damaged at P.

235 A long flat series of waves, with no distinct main, beginning soon after the end of the preceding shock. The flat waves of about 20 sec. period certainly do not belong to the tail of the first quake.

237. Beginning lost in change of records at $16^h\ 19^m$. W — EW record of quake not distinguishable among the microseisms.

239. B — NS has slight motion but time cannot be read because the record is poorly smoked.

241. No phases distinguishable. Long waves begin gradually, period 17^s to 20^s.

242. W — EW not running.

243. Long flat waves $7^h\ 38^m$ to maximum at $7^h\ 47^m$, then gradually decreasing.

244. Long flat shock. Period about 17^s.

245. Time marker of B—EW, W—EW and W—NS not working. Fair agreement in estimated time. Main lasted about 1^m.6.

246. Time markers of B — EW, W— EW not working. Good agreement estimated. A peculiar disturbance. Waves 6 — 8 seconds, no long waves. During the first part waves of shorter period superposed. Beginning not clearly defined.

247. Time marker not working. Long period, flat waves persisting about 15 minutes.

249. W — V had slight response at $18^h\ 14^m$ followed by feeble oscillations. Two sets of long waves. The faster about 220 km. per min., the slower 200 km. per min. The slower waves were the stronger.

251. Distance probably about 5.0 mgm. Phases similar to Dec. 21 quake.

252. Strong short waves are superposed on the long, which make L very uncertain. This is the Guatamala quake. The interval P to S gives fair determination of distance.

253. "Parallax" of B — EW not known accurately, 0.5^m correction was used. F is mingled with micros. B — NS gave a feeble response. Phases on the EW components not clearly defined.

254. The intervals P to S and S to L appear discordant in this shock.

255. The time of the disturbance at the epicenter O = $21^h\ 18.7^m$. A very strong impetus at S produced an amplitude of 1.5 mm. on B — EW.

256. Long flat waves. Beginning and end lost in micros. W — EW tracer out of position; record superposed on W — NS. The W — NS record is very peculiar. The period is discernable by a succession of dots on the sheet, where no amplitude is seen. (Instrumental effect from W — EW?)

259. Perhaps includes a second shock about $19^h\ 45^m$.

Feb. 12. Possibly a shock at $17^h\ 19^m$ lasting a few minutes, visible on EW instruments and on W — NS.

Feb. 13. A slight shock about $3^h\ 57^m$ to $4^h\ 5^m$, no phases apparent.

262. May be PS instead of S. Other maxima occur at $7^h\ 18.3^m$ and $7^h\ 28.2^m$ on the NS components.

264. A series of impulses followed by irregular waves gradually weakening occurred shortly after records were changed.

267. May not be seismic.

269. S not clearly defined. Distance from W — NS.

270. O = $22^h\ 32.4^m$.

271. The amplitude was so great that the pen left the sheet on W — EW and the Bosch records.

272. F lost in micros.

273. The maximum appears before the long waves are detected.

276. O = $17^h\ 55.4^m$. B — EW ran down before the second shock began.

277. Wiechert not working properly. B — EW record shows instrumental defects. O about $18^h\ 57.1^m$.

279. B — EW "parallax" uncertain. F in micros.

280. B — EW and Wiechert time markers not working.

282. PS is much stronger than S on both components. Good record on Wiechert horizontal, but time marks are lacking. O = $21^h\ 25.8^m$.

284. Slight trace on Wiechert horizontal.

285. O = $3^h\ 58.7^m$. Δ and O determined from W — NS record which is clearly defined though amplitude is small.

289. May not be seismic.

290. No distinct main. Phases on B — NS not clearly defined. W — NS poorly smoked.

291. Phases uncertain.

292. W — NS First impetus produced an oscillation whose amplitude continued nearly constant for two minutes then decreased. PS appears stronger than S on the EW components.

293. O = $6^h\ 26.3^m$. Long smooth waves continue for about an hour on B — EW. B — NS poorly smoked. S not clear on B — NS and Wiechert.

294. B — NS time mark uncertain due to lateral displacement and poorly smoked paper.

295. Wiechert not running.

Aug. 15. A second shock occurred while the sheets were being changed.

297. P and L not clearly defined. Wiechert EW poorly smoked.

298. Impetus followed later by some long waves. No phases.

299. Slight quake. Time markers not working on B — NS and Wiechert.

300. Sheets changed during quake excepting on B — NS. Distance determined from P and L. S not identified. An impetus at $18^h\ 38.4^m$ is prominent on the Bosch records, also a second maximum at $18^h\ 7^m \pm$.

301. A slight disturbance lasting several minutes.

302. B — NS gives a thickening of the line at P. Record poorly smoked beyond that point.

Sept. 30. Quake occurred about 14^h to $14^h\ 30^m$. Record changed during the disturbance. A second quake giving a long flat record took place 19^h to 20^h, phases not defined.

304. O = $14^h\ 14.3^m$.

305. Phases not clearly defined.

307. The time of the emergence of the long waves is not certain.

308. Wiechert not running. O = $3^h\ 42.8^m$.

309. Records removed at $16^h\ 28^m$, disturbed earlier. Wiechert stopped Oct. 26, $23^h\ 42^m$, set Oct. 27, $22^h\ 26^m$.

310. Phases are not distinguishable.

311. Wiechert not running.

315. O = $21^h\ 45.4^m$.

316. A series of impulses appear on the records at $19^h\ 0.7^m$, $19^h\ 3.4^m$, $19^h\ 4.3^m$ and a change in the form of wave at $19^h\ 21.2^m$.

Nov. 22. Records changed at $16^h\ 30^m$. Disturbance follows but no phases can be read.

318. O = $9^h\ 47.4^m$.

319. Sheets changed at $14^h\ 50^m$, tremors still visible.

320. O = $8^h\ 40.7^m$. Time markers not working on Wiechert.

324. Time markers not working. P about $9^h\ 33^m$ and distance is 4.8 mg. by scale.

326. Wiechert time markers not working. Distant shock; phases not well determined.

327. Phases do not appear to agree on the two components. A series of impeti occur on the NS record at $3^h\ 27^m.3$, $31^m.9$, $36^m.7$, $39^m.4$, and $42^m.7$. Parallax of NS uncertain.

329. L uncertain. Waves with period of 9 seconds began about $12^h\ 2^m$.

330. Bosch E — W not running.

341. NS component very weak.

343. PS. appeared stronger than S which was not clearly defined.

347. Phases not discernible.

June 29. Italian quake record not obtained as sheets were changed about $15^h\ 15^m$ — 20^m.

349. O = $7^h\ 4^m1$. The phases are not clearly defined on W — NS.

350. P is masked by micros.
W — NS record rubbed.

351. An amplitude as great as the recorded M occurred at $19^h\ 36^m.8$. W — NS record is faint, but continues until $20^h\ 10^m \pm$.

352. Δ determined by P and S.

353. O = $22^h\ 1^m.3$. B — NS stopped after S.

354. An impetus is visible on the NS components at $17^h\ 20^m.5$; may not be P.

August 27. A disturbance occurred about $5^h\ 45^m$ and lasted an hour, but no phases are discernible.

355. Interpretation is difficult.

357. Impossible to interpret.

360. Heavy microseisms prevent reading the earlier phases.

362. Long waves continue for about thirty minutes. A distant shock, but the phases are not clear.

363. A distant quake, but the phases are obscured by micros.

365-366. Phases not discernible.

368. The long waves continued for about twenty minutes.

369. Beginning of long waves not definitely defined.

370. Microseisms. No distinct maximum.

371. Very probable that "e" occurred sooner. Apparently two quakes; one lapping over the other. No secondary waves perceptible. Δ determined from P and L waves, as interpreted.

372. Long waves were only ones which showed any degree of definition. Other waves were lost in microseisms. F likewise lost.

374. A difficult record. Preliminary waves entirely and secondary waves nearly lost in microseisms.

375. Beginning of preliminary waves not sharply defined. Long waves followed those recorded.

376. Emergence of P waves not definite.

377. B — EW out of order.

378. Microseisms.

379. B — NS tracer was not working properly.

380. Entire record composed of long waves.

381. Interpretation doubtful. P and S waves not prominent.

382. Microseisms.

383. Microseisms.

384. Nothing shown on W — EW. L waves determined from P and S waves. PR_1, PR_2, and SR_1 afforded excellent check.

386. Emergence of P waves not well defined. Long waves followed the second maximum.

387. Time marker on B — NS was not working. Nothing shown on W — EW nor W — NS.

388. Time marker on B — NS was not working. Nothing shown on W — EW nor W — NS.

389. Microseisms shown on B — NS but time marker still not working. Nothing shown on W — EW and W — NS.

390 Time marker on B — NS not fixed to date.

391. A faint shock. Weichert instrument not working properly. Δ is perhaps in error due to insufficient data.

392. A weak shock.

Sheets were off from $1^h\ 33^m$, Aug. 20, 1920. to $17^h\ 30^m$, Aug. 20, 1920.

395. Time markers failed to work properly on B —NS, W — EW and W — NS.

396. Instruments not running during the first part of the disturbance.

397. Δ determined from L and S.

401. Microseisms.

406. E. W. component not working.

407. F was lost in microseisms.

Machines stopped from $3^h\ 30^m$ Nov. 25, 1920 to 22^h Nov. 26, 1920, and from $4^h\ 12^m$ Nov. 27, 1920 to $16^h\ 45^m$ Nov. 28, 1920.

414. Time markers on B — EW and B — NS not working.

415. Microseisms present made interpretation rather difficult.

416. F lost in microseisms.

417. Several long waves followed the maximum at intervals through fourteen hours.

418. Microseisms throughout the record. Amplitude of quake about the same as that of microseisms.

419. Microseisms throughout record.

420. Very faint.

423. Continuous microseisms present. Quake difficult to interpret.

430. Long waves occurred at $19^h\ 15^m$ and at $19^h\ 25^m.6$.

432. A maximum occurred at $16^h\ 36^m.7$ on all records. The interpretation given may be questionable for microseisms were present quite continuously.

433. Very similar to 431.

434. A quake occurred the latter part of Feb. 27. The time markers were out of order, so an accurate interpretation of quake was not possible.

441. No preliminary waves were shown.

442. Long waves followed at $0^h\ 51^m.2$, $0^h\ 53^m.9$ and $0^h\ 58^m.4$.

443. B — NS was not working.

444. Waves very faint and not well defined.

451. Long waves started at about $18^h\ 9^m.2$ and continued for some time.

453. S waves not well defined. Interpretation may be slightly in error because time markers failed to work properly. E. W. components gave best results.

455. Waves of varying lengths followed.

456. Very faint.

457. Precipitation in fixing liquid blurred the sheets, so marks were difficult to see.

458. Emergence about $22^h\ 09^m.0$.

The machines were dismounted June 14 in order to paint the seismograph room and to clean and repair the instruments. They were re-assembled July 14, 1921.

460 and 461. B — EW component was not working well.

462. Sheets on the B — NS component were scorched while being smoked.

465. Very faint.

466. Emergence at $20^h\ 17^m.5$. Values corresponding to PS, SR, and SR_2 checked well with other phases.

467. Not typical long waves; time marker on B — NS component not working.

468. Time marker not working on B — NS component. L waves at $20^h\ 36^m.6$, $20^h\ 47^m.9$ on B — EW component.

469. Emergence at $19^h\ 32^m.6$ on B — EW component.

471. Time marker not working on B — NS component. Waves show on this component, but they are not as pronounced as on B — EW component.

473. NS waves are the weaker ones.

475. Emergence of L waves not well defined. PR_1 and SR_2 checked well with other phases.

477. A second maximum followed at 7^h. Weak on EW component.

478. O about $18^h\ 44^m.5$. Short waves appear at $19^h\ 55^m$ following the main shock: perhaps another quake.

480. O about $20^h\ 37^m.6$.

Nov. 23. A strong impetus of unknown origin, probably not seismic, occurred at $20^h\ 32^m$.

482. No distinct main.

A PICTORIAL STUDY OF THE SPECTRUM OF NOVA GEMINORUM II

By RALPH H. CURTISS

Reproductions of spectrograms of Nova Geminorum II, to present a pictorial study of the features brought out in the Detroit Observatory plates, were prepared some years ago. After much delay, occasioned by lack of funds, their publication now, it is hoped, will give a clearer impression of the changes in the bolder aspects of the spectrum of this nova than words could possibly convey.

All spectra concerned were photographed with the Single-Prism Spectrograph in combination with the 37½-inch reflector. The enlargements, as well as all others in this volume, were made with the special apparatus described on page 182 of Volume II of these *Publications*. Discussions of the various reproductions of the nova's spectrum are given below.

PLATES A, F, G, AND H.

These four plates are intended to give a pictorial history of the spectrum of Nova Geminorum II, as complete as our observations made it, from our first spectrogram, of March 13, made about a day before maximum brightness, to the end of our series when the exposure time had increased to four hours and more. The record is fullest in the photographic region (Plate A, the frontispiece) from the beginning until the observations were interfered with by the Sun in May. The first enlargement, that of March 13, is from the first record of this nova's spectrum secured anywhere with a slit spectrograph. The record in the same region is continued on Plates F and G during a month of interesting changes from December 8, 1912, to January 8, 1913. A series of three photographs in Plate H extends the earlier history of the spectrum into the visual region for a brief interval. In each case the magnitudes are taken from a curve based on Table V of the memoir by L. Campbell in *Harvard Annals*, Vol. 76, p. 191. Maxima and minima are indicated. The dates are expressed in Greenwich mean time.

In connection with Plate A attention may be called from the very beginning of the series to the presence of emission, increasing in prominence as the absorption lines, which predominate at the beginning, decline and disappear from view. The prominence of hydrogen, calcium, helium, and iron with bright and dark lines in nearly all cases is notable at the beginning of the series. On March 22 other Orion lines are appearing first as absorption and later with emission. By March 26 some of these new emission lines become conspicuous at λ 4641. By April 7 the iron emission is fading out while helium emission at λ 4472 is strong and the group of Orion emission lines at λ 4640 dominates the spectrum. Nebular lines in the photographic region appear faintly on the Detroit Observatory spectrograms on April 15. On the spectrum of April 27, λ 4363 of nebulium is well shown. N1 and N2 of nebulium are outside of the region included on Plate A but may be seen for the first time on these reproductions in the spectrum of May 9.6 in Plate F.

In Plate F the greatly increased strength of the nebulium lines in the interval from May 9, 1912, to December 8, of the same year, is most notable. Also the group centering about λ 4640, which, though subject to many fluctuations, was a persisting feature of the nova's spectrum, is very strong on December 8 and 9. The spectra of these two days were photographed very nearly at the maximum of one of the many recovery phases that marked the nova's decline. Subsequently the brightness of this star diminished as the indicated magnitudes show. With this decline interesting spectral changes occurred, clearly seen in the reproductions.

On December 8, Hβ and N1, Hγ and λ 4363, form pairs of bright bands of nearly equal width and intensity. N2 is much fainter. All have emission maxima at their edges. Extensive wings accompany the hydrogen lines which are faint in the case of Hβ, easily visible on the violet edge of Hγ and strong on both edges of Hδ. On the side of shorter wave-length the wing at Hδ is interrupted by a wide dark interval with center at λ 4075 but seems to begin again at λ 4065 and fades into the continuous spectrum at λ 4050. The strong emission group at λ 4640 shows a similar structure. In this case the supposed violet wing is interrupted by a wide dark interval at λ 4585 but continues at λ 4570 and finally disappears at λ 4490, with bright λ 4472 of helium nearby. Other interpretations of these wings of emission near the hydrogen lines and λ 4640 are possible, but that they are related to the lines they accompany is strongly suggested by their appearance in the case of hydrogen and, perhaps less clearly, in the case of λ 4640. In the latter case to account for the emission centering at λ 4530 we have λ's 4511 and 4515 of nitrogen and λ's 4518 and 4542 of helium to draw upon. But whatever the nature of the wings they change very rapidly for on the next day emission occupies the place of the dark interruption, a dark band flanks the new emission on the violet edge, and beyond this new or displaced dark band the wing is faint if indeed it is present. Also in the interval of a day the maximum in the nebulium lines in the edge of shorter wave-length has developed superior strength, whereas the maximum in the opposite edge had been strongest twenty-four hours before.

On December 13, the group at λ 4640 has broken up into three bands, λ's 4610, 4641, and 4686; and λ 4363 has become distinctly brighter than Hγ, N1 than Hβ, and N2 is nearly as strong as Hβ. In absolute intensity the hydrogen lines have diminished whereas the nebulium lines have at least held their own. The rise of λ 4686 is notable.

With the decline in the nova's light the hydrogen lines continue to fade and the nebular lines to stand out more strongly as shown in the last two spectra of Plate F.

In two of these spectra sharp absorption of calcium H can be measured in the weak absorption of Hε. These measures yield a velocity of +10 km., which accords well with values obtained from this line at the time of the nova's discovery.

In Plate G features that are overexposed in the last five spectra of Plate F are brought out by deeper printing. The structure, especially in the nebulium lines of December 9 and the hydrogen lines on all dates, is most interesting. The changes in relative strength of hydrogen and nebulium lines as described above are well brought out in this plate.

Plate H, in the visual region, brings out many bands, emission and absorption, including those of enhanced iron and the D lines, the latter with sharp, undisplaced absorption components as well as wide emission and strongly displaced absorption. On March 27, with declining light, the emission stands out strongly. Some bands have disappeared and new ones which may be ascribed to nitrogen or to nebular origin have come in. Double and triple displaced absorption is well shown in Plate H as in spectra of the same dates in Plate A.

PLATE I

The reproductions assembled in this plate are intended to bring out the spectral affiliations of Nova Geminorum II at the time of its discovery. Attempts to assign the spectrum of this and other novæ at the earliest stage to normal stellar classes has led undoubtedly to false impressions — to the idea that these objects emit normal spectra even though they are undergoing great light changes. In Plate I the early nova spectrum is placed in proximity to well known spectra with which comparison has been made or seems profitable.

The comparison of the spectrum of Nova Geminorum II on March 13, 1912, with that of Procyon, at the bottom of the series, brings out the resemblance in the bolder absorption features, the hydrogen and the calcium H and K lines, but it is a resemblance that can be followed little, if any farther. The indentity of many of the absorption lines in the nova's spectrum with enhanced metallic as well as hydrogen lines in α Cygni and with many of the emission lines in φ Persei is brought out in the upper section of the plate. If the spectrum of φ Persei were

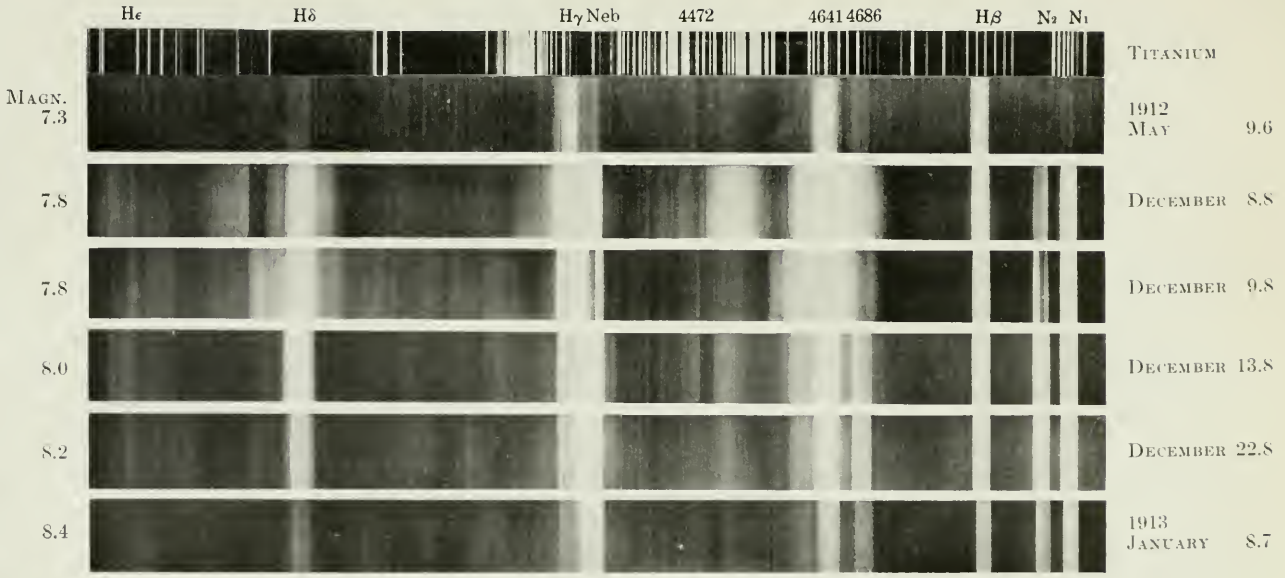

Plate F. Spectra of Nova Geminorum II in the Nebular Stage

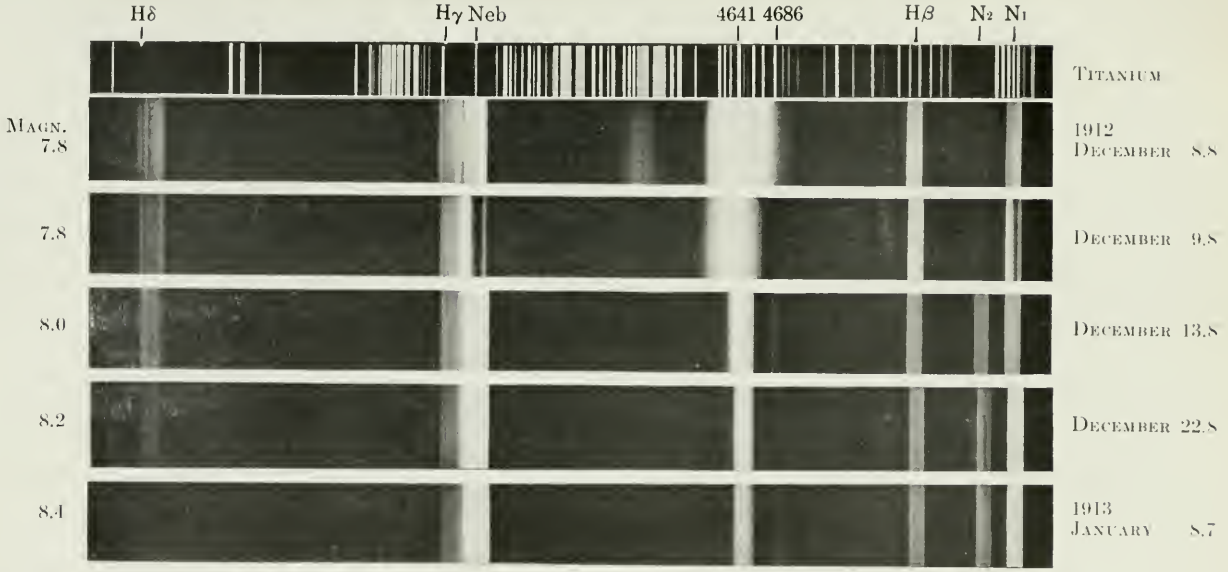

Plate G. Spectra of Nova Geminorum II Showing Structure of Emission Bands

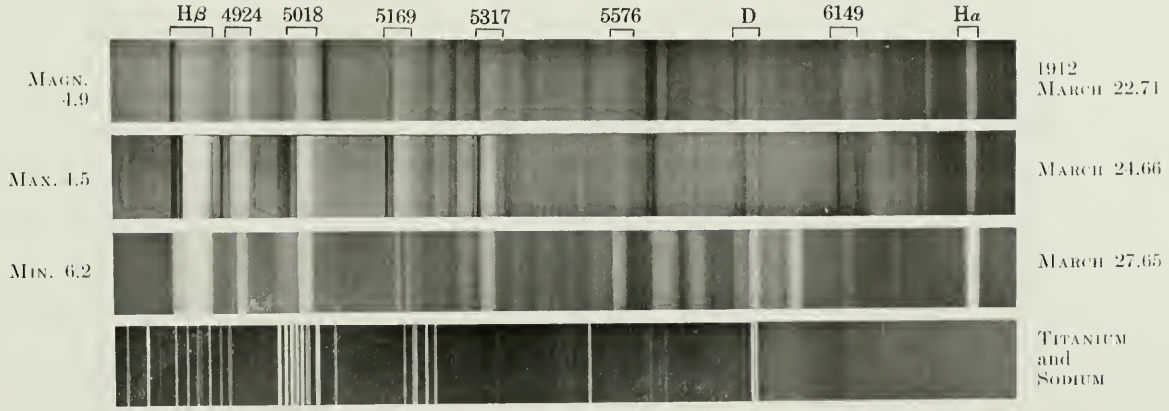

Plate II. Spectra of Nova Geminorum II in the Visual Region

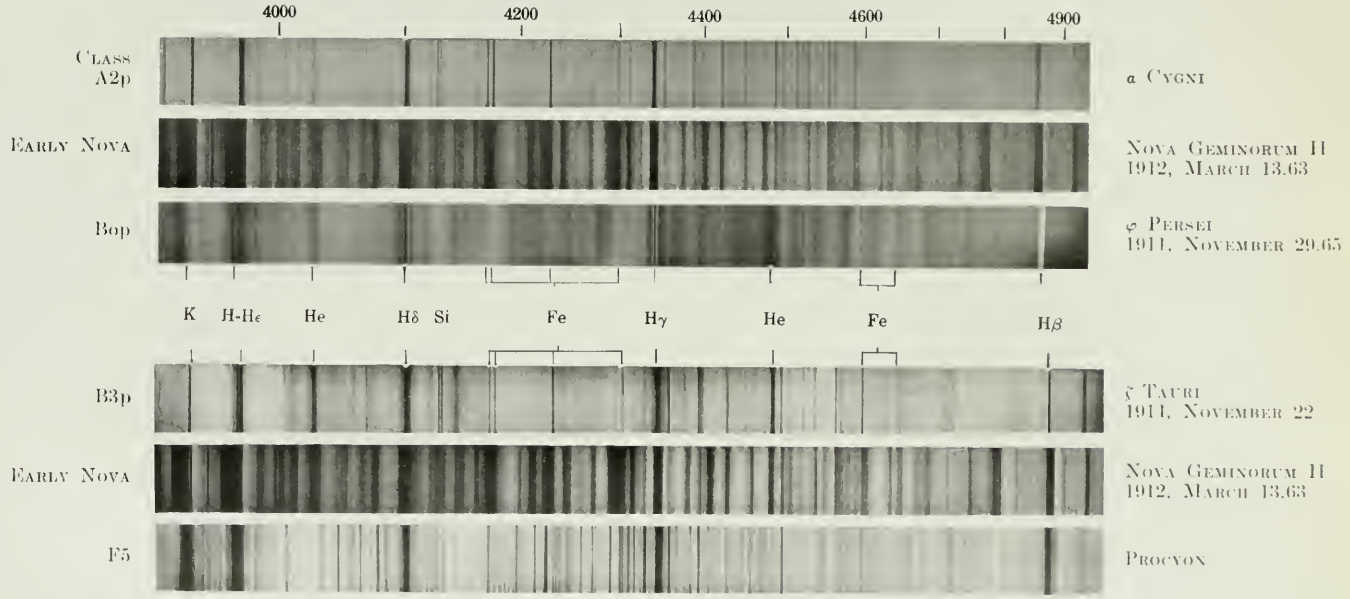

Plate I. Comparison of the Early Spectrum of Nova Geminorum II with Those of Other Stars

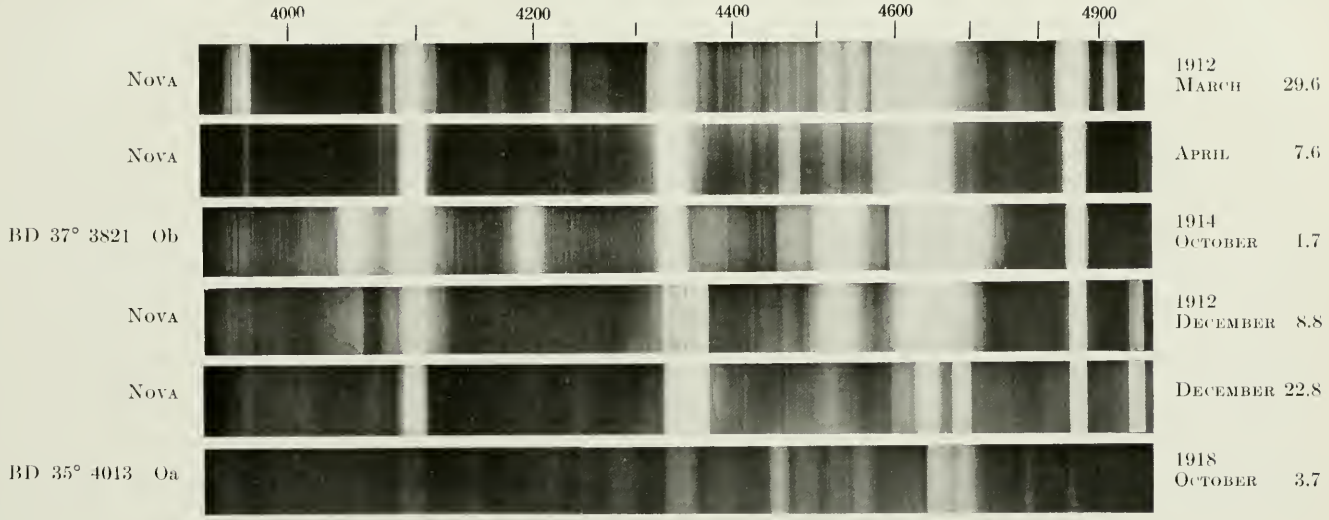

Plate J. Comparisons of Spectra of Nova Geminorum II with Oa and Ob

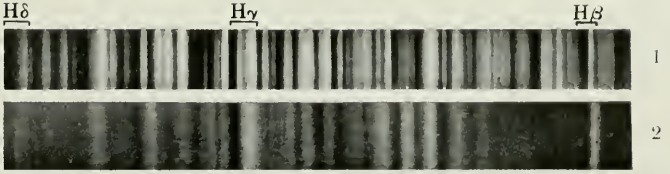

Plate K. 1. Nova Geminorum II. 1912 March 13.67

2. Nova Aurigæ. 1892, February 9.

[By W. W. Campbell]

displaced a short distance to the right many of its emission lines would correspond to identical emission lines in the nova's spectrum. The helium lines in the nova, of which two are indicated, are fairly strong and find somewhat comparable counterparts in the spectrum of ϕ Persei. But these lines are relatively weak in α Cygni, and this is one notable point at which the remarkable correspondence between the lines of the nova and α Cygni breaks down. In the spectrum of ζ Tauri a striking correspondence with the nova for both helium and iron absorption is found, as shown in the lower group of Plate I. But the nova spectrum does not exhibit accurate resemblance to any so-called normal stellar spectrum and is limited in its identities with other peculiar spectral types.

PLATE J

The spectra in this group are brought together to bring out resemblances and differences among spectra of Classes Oa and Ob and those of Nova Geminorum II in the "λ 4640" and nebular stages. These comparisons were inspired by Sir Norman Lockyer's wave-length studies (*On Some of the Phenomena of New Stars*, 1914, pp. 50 and 52) which led him to remark with reference to Wolf-Rayet stars and novæ in the nebular stage, "The hydrogen lines are common, but apart from them there is no known element represented in both types of spectra." Also we have the statement, "Thus we find a general similarity between the spectra of the 'λ 4640 stage' of novæ and the Oa (Wolf-Rayet) spectra, a similarity which extends to practically all the features exhibited by these spectra." Lockyer selected a star in Carina for his best Oa counterpart of the nova and uses the spectrum of the nova on April 15 for comparison at the "λ 4640 stage." In Plate I the Detroit Observatory spectrum of April 7 is used for the nova because it shows much detail, but the spectrum of April 15 may be referred to on Plate A. The Class O stars on Plate J are representative northern objects.

The resemblances connecting all the spectra in Plate J are very striking. Emission bands of comparable breadth of hydrogen and probably of λ 4472 of helium are common to all. Also strong broad emission at λ 4640 characterizes each spectrum. Possibly there is a central emission band at λ 4641 ± that is of the same nitrogen origin in each spectrum, except in BD. 35°4013 in which absorption appears closely in this position and a band which may be due to carbon emission is seen at about λ 4650. Also λ 4686 of helium is common to the nova nebular spectra, to those of Class Oa and Ob, and possibly to the nova spectra of April 7 or 15. But it is quite improbable that all of the emission in this band is of the same origin in all six spectra.

A distinctive feature of the first two spectra is the array of iron emission bands which, however, are fading out at this stage of the nova's history. A distinctive feature of the nova spectra in December is the emission of nebulium in N1, N2, and λ 4363 (the former is shown in Plates G and H). A distinctive feature of the Class O spectra is the ζ Puppis helium emission at λ 4200 and λ 4542. Other differences are notable but these are probably fundamental and keep these spectra apart. It is later in the nova's history that the Class O stage appears.

PLATE K

On this plate a comparison is made between the spectrum of Nova Geminorum II a day before the maximum light was reached, at a time when the spectrum was not considered as of "nova type," with that of Nova Aurigæ when in the latter object nova spectrum characteristics were well developed. This comparison brings out a striking resemblance between the two spectra. Comparison with Plates A and I show that the photographic contrast in the upper (Nova Geminorum's) spectrum has been heightened in copying, but the resemblance noted would hold if this were not the case. Undoubtedly continuous radiation forms a much stronger background in the upper than in the lower spectrum of Plate K, whereas emission stands out in the lower one, but it is quite certain that hydrogen and metallic emission is common to both stars and contributes to their similar character. This comparison as well as that between the first two spectra of Plate A suggests that the spectrum of Nova Geminorum II on March 13, 1912, was not far different from that of so-called nova type.

SOME BRIGHT LINE STELLAR SPECTRA

By RALPH H. CURTISS

PLATE B

This group of eight bright line spectra is headed by two examples of early nova stages taken from the Detroit Observatory series of spectrograms of Nova Geminorum II. These are followed by representatives of stellar spectra in Class Bp, the first two of which are of so-called P Cygni type in which emission and absorption in the same line are found side by side. Then follow three well known spectra with doubly reversed lines and finally ζ Tauri with less conspicuous emission.

This entire group furnishes in the features ascribed to hydrogen and helium a series of gradations from abnormal to conventional spectral lines. If now we except the spectrum of P Cygni itself, which could be compared more profitably with later examples of Nova Geminorum's spectrum, the remaining seven plates constitute a series in which metallic emission with absorption traverses the whole.

These spectra have been grouped together to facilitate comparison of peculiar features which may be manifestations of effects due in each case to similar exciting stimuli. The group is not intended to suggest a sequence of spectra corresponding to successive stages in stellar development, though it might be profitable to consider the last four spectra in this connection. This plate was prepared for reference in connection with the discussion, in the second paper of this volume, of the possibility that the spectra shown are emitted by stars whose spectral peculiarities are due to similar abnormal disturbances. In the paper referred to, discussion is found concerning possible stimuli acting on the atmospheres of these stars.

PLATE C

This plate depicts characteristics of two striking spectra of Class Bp, from Hγ to the limit of the record of the Balmer hydrogen series in the ultra-violet. In the spectrum of ζ Tauri emission is visible on the edges of the Hβ and Hα lines (See Plate B for Hβ) and on the edges of a number of metallic lines. This emission is undoubtedly present at the edges of the hydrogen lines well toward the limit of the Balmer series though not set off by absorption borders as in many spectra of Class Bp. The presence of this emission probably results in the remarkable definition of the metallic lines and especially of the hydrogen series as also in the similar case of α Cygni. In 11 Camelopardalis' spectrum sharp central emission, accentuated by bordering absorption, defines the hydrogen series unusually far into the ultra-violet and metallic lines are brought out well by emission borders. In the spectrum of ζ Tauri the lines in the hydrogen series can be seen to H30 or H31 and perhaps farther. In the spectrum of 11 Camelopardalis the central emission in the hydrogen series can be seen to H7. The computed head of the hydrogen series is almost exactly at the left end of the two spectra. Beyond the head the continuous spectrum does not show on the two plates. Probably the intensity curve of the continuous spectrum of ζ Tauri is not far different from that found by Wright for α Cygni (*Lick Observatory Bulletin*, No. 332), a decline beginning at about λ 3700 and dropping sharply to the Balmer limit. In the spectrum of 11 Camelopardalis the overlapping absorption borders of hydrogen terminate the recorded continuous spectrum farther toward the red.

These two spectra will be useful in wave-length studies of the lines of hydrogen near the Balmer limit.

TYPICAL STELLAR SPECTRA

By W. CARL RUFUS

The purpose of this work, the photographic enlargement and reproduction of typical stellar spectra, is to present by a series of plates the chief classes of stellar spectra and to illustrate the changes of the chief spectral characteristics with the sequence,

$$P\ O\ B\ A\ F\ G\ \begin{matrix} K & M \\ R & N \end{matrix}$$

The spectrograms used for the enlargements were made with the one-prism spectrograph attached to the $37\frac{1}{2}$-inch reflecting telescope of the Observatory of the University of Michigan. At the beginning of the work selections were made from spectrograms on hand, that had been obtained in connection with the regular observational programs. It was soon found, however, that these were unsatisfactory in general on account of differences in slit width, differences in the emulsions of the photographic plates used, and change in the dispersion of the spectrograph when the new prism was installed. Consequently a number of new spectrograms were made, using as far as practicable an adopted slit width and Seed 23 plates. For faint stars a wider slit and a coarser emulsion were necessary.

The region of the spectrum selected for enlargement extends from about λ 5100 to about λ 3900, which includes the lines N_1 and N_2 of the hypothetical element nebulium near the end of greater wave-length and the H and K lines of calcium near the end of shorter wave-length.

On account of the difference in sensitivity of the photographic plates for rays even of this limited range of spectrum, and on account of the greater difficulty due to the difference of the relative intensity of the violet light in spectra of the various classes, several devices were used in the attempt to produce a photographic spectrum showing detail throughout the entire selected region. For example, in order to obtain a spectrogram of a red star strong enough to show the H and K region without overexposing the region near Hβ, the slit of the spectrograph was kept in the ultra-violet part of the spectral image of the star, thus taking advantage of the elongation of the image produced by atmospheric refraction. In this case the guiding was done by keeping the image of the slit entirely free from the visible image of the star on the side of shorter wave-length. Shading regions of the enlarged positive during the exposure to produce the final negative and shading parts of the negative during the exposure to make the prints were also necessary.

These artificial devices, added to the inherent difficulties, tended to complicate the problem of preserving the relative intensities of lines in a single spectrum and especially in representing the progressive changes in intensity of several separate characteristic spectral features from one class of spectrum to the one following in the spectral sequence. From the nature of the work, therefore, the resulting reproductions represent compromises among these conflicting elements of the problem, and the intensities of the spectral characteristics here presented must be considered qualitative rather than quantitative.

Twenty-eight spectrograms reproduced in the accompanying plates have been selected and arranged to represent the chief classes of stellar spectra and to indicate the changes of the chief spectral characteristics with the sequence. It is well known that the vast majority of stellar spectra fall into this sequence, which is based upon the principle of relationship by resemblance. Only a surprisingly small number of peculiar spectra show no affinity for the members of this orderly series.

At the left of each spectrum reproduced in the accompanying plates, L, M, N and O, is given the class of spectrum according to the Henry Draper classification, now generally adopted;

and at the right is the designation of the star whose spectrum is reproduced, generally the one selected by the Harvard observers as the typical star. Plate L contains one nebular spectrum and one of each of the subdivisions of Class O. Plate M extends from Class B to Class G giving examples of spectra at intervals of five least divisions of the sequence, ten divisions marking the transition from one class to the next, e.g. from B to A. Plate N represents the end of the main branch of the sequence, including Classes G5 to K5 and all the subdivisions of Class M. Plate O represents the other branch of the sequence, G R N, containing enlargements selected from those made by Professor Curtiss and used to illustrate the author's article, The Spectra of Class R Stars, in Volume II of these *Publications*. The spectra of Plate O extend to a longer wave-length than the spectra of the preceding plates, but are cut off at the violet end just beyond the line H of calcium. At the top and bottom of each plate characteristic lines are designated.

The general characteristics of the spectral sequence are also well known and may be briefly summarized to serve the present purpose. The accompanying figure, Characteristics of the Spectral Sequence, graphically represents some of the chief features from the qualitative standpoint. The classes of spectra are the abscissæ and the relative intensities of selected spectral features are the ordinates. Below the horizontal line are emission or bright line features and above it are absorption lines and bands.

The behavior of hydrogen is especially interesting, as lines of only this element may be traced throughout the entire sequence. The emission lines of hydrogen appear in the spectra of gaseous nebulæ, only one of which is reproduced, and in the bright line spectra of the Wolf-Rayet stars, Classes Oa, Ob and Oc. The emission lines of hydrogen are replaced in Class Od by corresponding absorption lines, which increase in intensity with the sequence reaching a maximum in Class Ao, then decrease through the following classes of the sequence with bright lines appearing again near the end. The H and K absorption lines of calcium appear in Class O, even in the spectra of

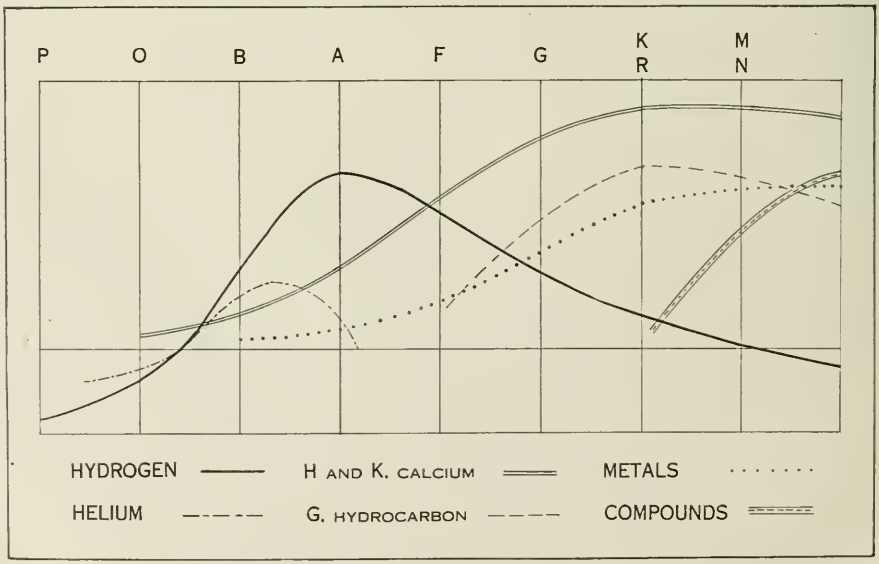

FIG. VI

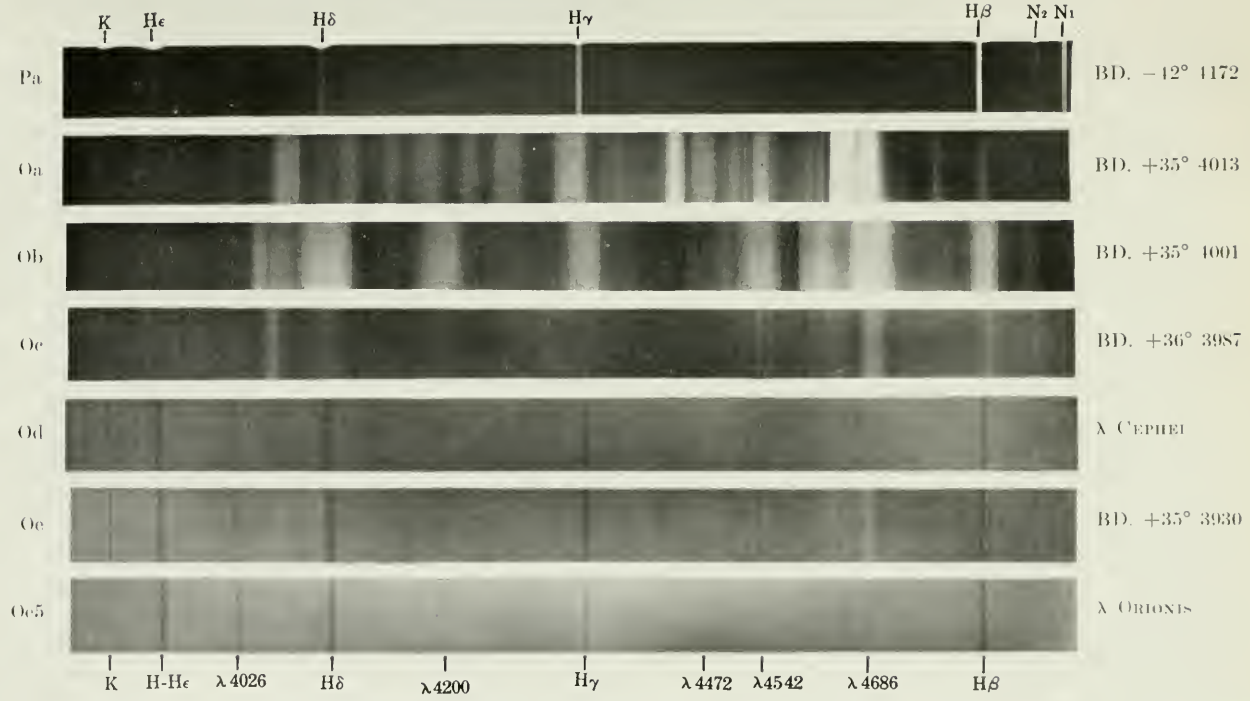

Plate L. Class Pa Nebular Spectrum and Class O Stellar Spectra

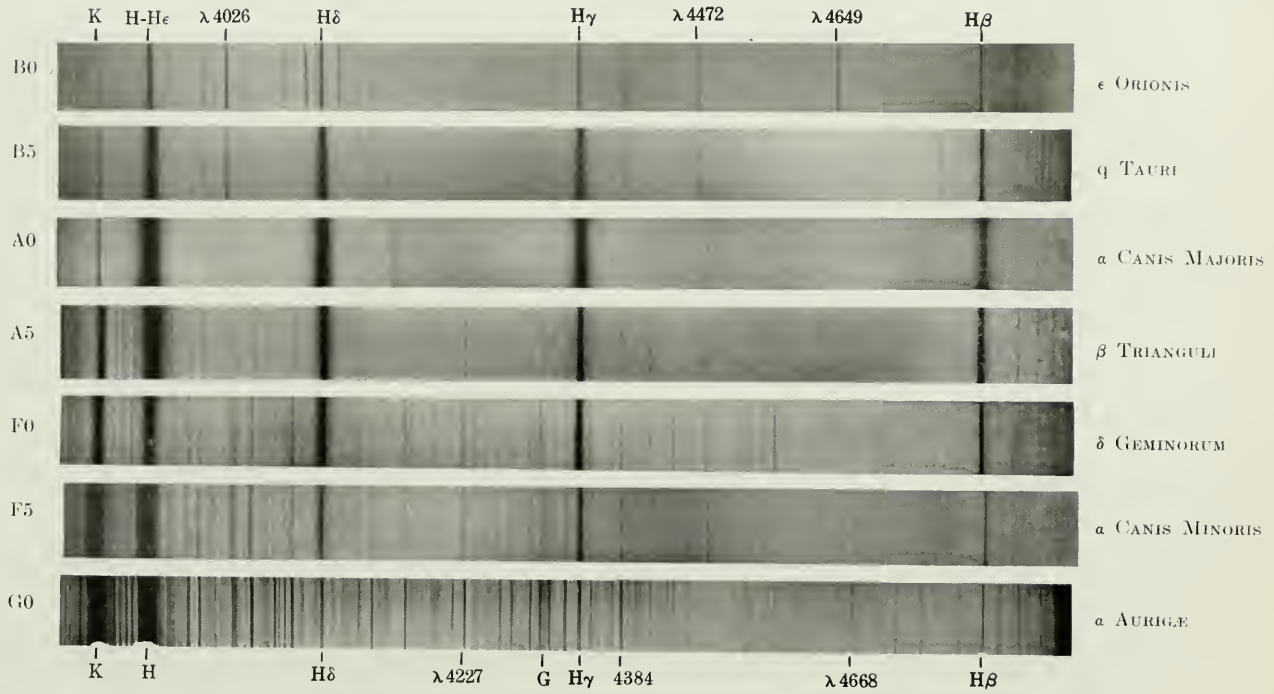

Plate M. Stellar Spectra from Class B0 to Class G0

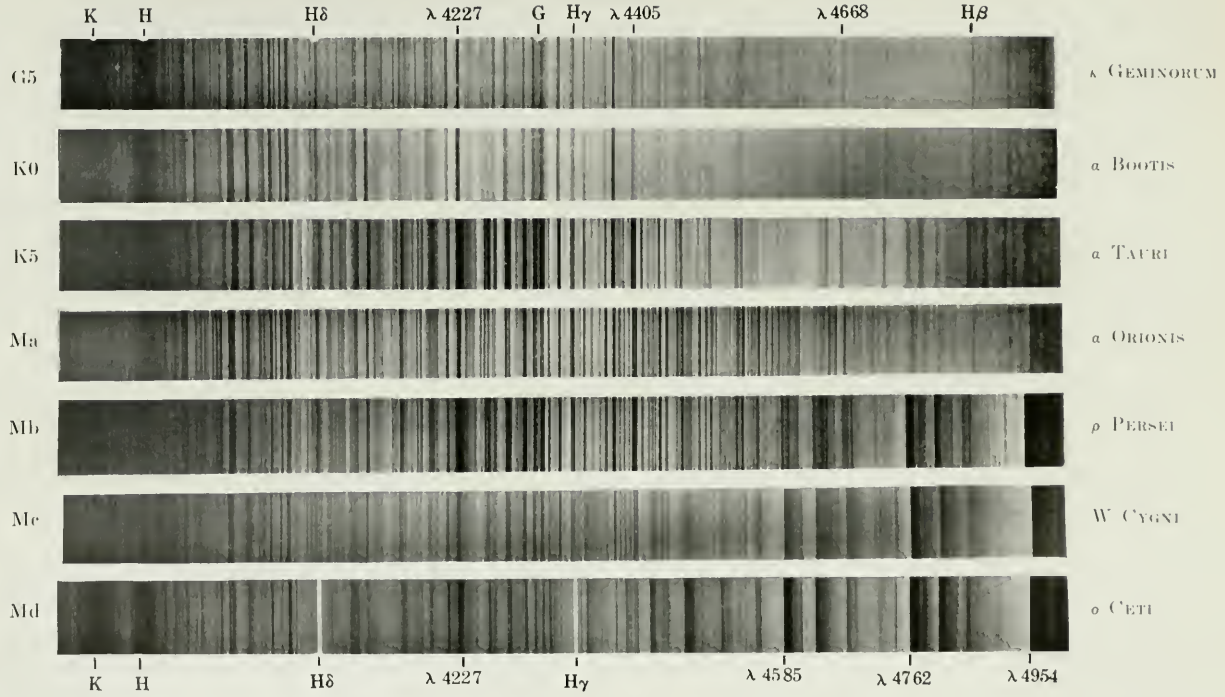

Plate X. Stellar Spectra from Class G5 to Class Md

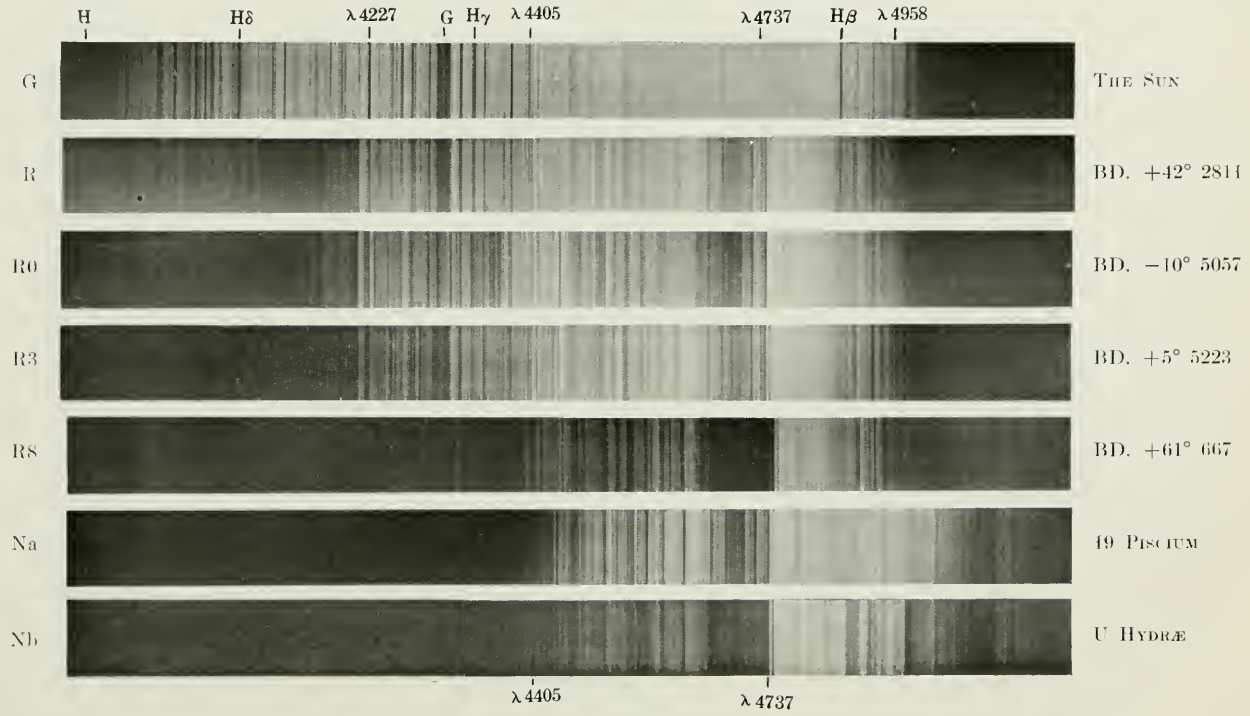

Plate O. Stellar Spectra of Classes G, R and N

some of the "bright line" stars, when sufficient exposure is given to produce a continuous spectrum in this region. The H and K lines continuously increase in intensity as far as Class K and remain strong in Class M. Sufficient exposure indicates their presence as strong lines in the spectra of some stars of Class R and Class Na; but in spectra of Class Nb weakness of the violet light renders their detection difficult and in some cases impossible. As the spectrograms used for Plate O were made for radial velocity and wavelength determination and not primarily intended for this work, the artificial strengthening of the relative intensity of the violet end is lacking. The other general features indicated by the figure may be followed through the plates representing the sequence.

REMARKS CONCERNING PLATE L

In addition to the hydrogen bright lines in the spectrum of the planetary nebula, BD. -12° 1172, the bright lines N_1 and N_2 of the hypothetical element nebulium are also conspicuous. Numerous bright lines and bands characterize Classes Oa, Ob and Oc. The ordinary lines of the elements hydrogen and helium are present, also the ζ Puppis series now attributed to helium, the Fowler line λ 4686 also attributed to helium, and numerous unidentified lines and bands. Especially strong in Class Oa are the wide bands with centers at approximately λ 4650, perhaps due to carbon and λ 4686 previously mentioned. λ 4441 is also strong in Class Oa but is not found in the other classes. In Class Ob λ 4686 is the special feature, while λ 4650 is lacking. The hydrogen bright lines are stronger than in the preceding class. The ζ Puppis lines λ 4542 and λ 4200 are prominent. Class Oc has a comparatively strong continuous spectrum which renders contrast difficult. The bright lines are weaker and narrower than in Classes Oa and Ob. λ 4686 is the strongest band. λ 4059 is strong and quite sharply defined. The H and K absorption lines appear stronger than in Ob. On some of our spectrograms of Class Oa, K is visible but H is lacking.

The transition from Class Oc to Class Od represents a change from a typical bright line to a typical absorption line spectrum. Indications of the changing process are suggested, however, in Class Oc by the absorption lines at the centers of some of the bright bands, expecially the ζ Puppis series, λ 4026, λ 4200 and λ 4542. A similar feature is seen in the region corresponding to the position of the band G of the solar spectrum. The reversal of λ 4026 may be traced back through Classes Ob and Oa, while bright borders of this line and others persist in Class Oe, which in our reproductions shows a closer resemblance to Class Oc than the intervening spectrum of Class Od.

Our spectrograms of λ Cephei, Class Od, show a slight strengthening of the spectrum at λ 4686 and λ 4638. The background of the reproduction is dark in order that these emission features may be preserved, but they are not clearly evident. Hydrogen dark lines are the most prominent features of Class Od and the following Classes Oe and Oe5. The ζ Puppis series, named after the other type star of Class Od, is strong in this class and the following ones. The ordinary helium lines are also present but not strong, increasing in intensity in Classes Oe and Oe5 as brought out clearly by λ 4472.

REMARKS CONCERNING PLATE M

The increase in the intensity of the hydrogen lines to Class Ao and the decrease through the following classes constitute one of the main features. The increase of calcium absorption is indicated by the lines H, K and λ 4227. Helium decreases in intensity from Class Bo as noted by λ 4472 and λ 4026. The carbon line, λ 4649, is also at maximum intensity in Class Bo. λ 4481 of magnesium increases in strength from Bo to Ao where it becomes the most conspicuous line excepting the hydrogen series and K of calcium. The increase in the intensity of metallic lines may be illustrated in numerous cases, for example, λ 4384 and λ 4668. The increase in the number of metallic lines is also a special feature. The development of the band G may be traced.

REMARKS CONCERNING PLATE N

The hydrogen series is no longer prominent. H and K are broad and strong, but due to the weakness of this region of the spectrum it was difficult to show their intensity compared with other lines. The calcium line λ 4227 is prominent

and increases in intensity through Classes G and K. The band G is conspicuous and appears almost continuous in Classes G5 and K0 with weaker absorption at the center; but becomes weaker and loses continuity in the following classes. The increase in the intensity of the iron line λ 4405 is noteworthy. Other iron lines showing large change in intensity with spectral class from F to K or M are λ 4326 between Hγ and G, λ 4352 blended with magnesium, seen just at the right of Hγ, and λ 4383 at the left of λ 4405, making with it a conspicuous pair in Class K5, both components of which are strengthened by blending with close lines. These four iron lines and the calcium line λ 4227 are used by Adams and Kohlschütter in comparison with Hγ to form intensity ratios in their quantitative method of spectral classification. λ 4872 and λ 4958 compared with Hβ are also used in the same way. The lines strengthened in high luminosity stars, λ 4216, λ 4395 and λ 4408, blended with λ 4405 in our reproduction, may be noted in the spectrum of α Orionis.

The banded appearance typical of all Class M spectra begins to show in Class K5 and is most strongly marked in the last subdivision Md. The beautiful spectrum of o Ceti is also enriched by the presence of bright hydrogen lines, as well as the characteristic titanium oxide bands.

REMARKS CONCERNING PLATE O

The strong absorption band with head at λ 4737 usually attributed to carbon monoxide is one of the chief characteristics of Classes R and N. In general the band G is strong on plates showing this region of the spectrum, although it is lacking in the spectrum of the star BD. −10° 5057, which was selected at Harvard as the type of Class Ro. We have preceded the reproduction of the spectrum of that star by another BD. +42° 2811, which shows a closer resemblance to Class G than the selected type, with regard to strength of the violet light, intensity of the hydrogen lines, and weakness of carbon absorption. λ 4227 is strong in all Class R spectra photographed in that region. A drop in the intensity of the continuous spectrum at λ 4216 and another at λ 4396 are noticeable, Class N spectra being very weak on the violet side of the latter. Bright lines are present in some of the spectra of Class R stars and in Class N stars, but are not conspicuous. Our series ends with Class Nb; but another class, Nc, has been proposed at Harvard, the spectra of which show no light of wave-length shorter than Hβ.

NEW SILICON LINES IN CLASS B STARS

By W. C. RUFUS, R. A. SAWYER and R. F. PATON

It has long been recognized that the spectrum of silicon is very difficult to obtain in the laboratory. It has further been noted, by Lockyer and others, that very marked changes in relative intensity and appearance of the silicon lines are produced by varying the mode of excitation. It is also well known that results by different observers show wide variations in the number and wave-lengths of the lines measured.

The presence of silicon absorption lines in stellar spectra was early noted by Lockyer and by Huggins. At the present time nearly all the strongest silicon lines from λ 3700 to λ 6600 have been identified in stellar spectra. The progressive change in intensity of certain silicon absorption lines with stellar spectral class has been established by Professor Pickering and others. For example, λ 4089 and λ 4116 reach maximum intensity in Class Bo and decrease rapidly; while λ 4128 and λ 4131, which are stronger in the vacuum spark than the preceding, are absent or very weak in Class Bo, and increase in intensity throughout the succeeding subdivisions of Class B. It has also been noted that certain stars of the B subclasses have stronger silicon lines than others of the same decimal classification, and Professors Frost and Adams have pointed out that these same stars show a corresponding increase in the intensity of the oxygen and nitrogen lines. The anomalous behavior of silicon emission in P Cygni, a Class B star, having bright lines in its spectrum, has been discussed by Dr. Merrill and others. In the spectrum of this star bright lines, non-centrally superposed on broad absorption lines, show a displacement too great to be ascribed entirely to Doppler effect; while the displacement of the silicon emission lines does not agree with that of the other elements.

An investigation of the silicon spectrum has recently been made in the Physical Laboratory of the University of Michigan, by Professor R. A. Sawyer and Dr. R. F. Paton, using as a source the vacuum spark. Under the violent excitation used, there were emitted silicon radiations not previously observed. Many new silicon lines were revealed, increasing the known number about five fold.

It seemed to us of interest to compare the unidentified lines in the spectra of Class B stars with the newly found silicon lines for possible coincidences. In the spectrum of Rho Leonis, between λ 4089 and λ 4838, seven new coincidences were found by Professor Rufus, which are indicated in the lower part of the accompanying table. The first part of this table gives ten previously known silicon lines, of which seven were measured in the spectrum of this star. The first and second columns of the table give the wave-lengths and intensities of the lines in the vacuum spark, the third and fourth columns give the wave-lengths and relative intensities of the lines as measured in this star by Mr. B. H. Dawson[1], and the last column gives the differences of wave-lengths, spark minus star. The wave-lengths are expressed in Angstrom units in the International system. The relative intensities of the lines in the spark and in the star show an utter lack of correspondence; consequently, since silicon series relationships have not been definitely established, a consideration of the line intensities will give little or no aid in determining identities between silicon spark lines and stellar absorption lines. The differences in wave-lengths of previously known lines found in the spark and in the star led to the adoption of four-tenths of an Angstrom unit as the provisional maximum limit in recording coincidences. There is little reason to doubt that the seven close coincidences in the case of Rho Leonis represent new identifications. Five of these seven lines are members of pairs having the same frequency difference as the pair, λλ 4088.88 — 4116.15.

Since a stellar source of light reveals a mixture of various elements, existing under different con-

[1] *Publications Detroit Observatory*, Vol. II, p. 159, 1916.

ditions in different stars, it may be of interest to consider some of the impurities of the silicon spark spectrum in relation to Class B stars. Of the seven lines attributed to oxygen by Professor Curtiss[2], from λ 4076 to λ 4661, in the spectra of δ Orionis and ε Orionis, all excepting the last one are found among our impurities. In a similar region of the spectrum, from λ 4076 to λ 4709, twenty-one lines in the spark are attributed to oxygen, of which all excepting three are given by Dr. Henroteau and Mr. Henderson[3] in their table of the lines in Class B stars. Four nitrogen lines in the spark are all found in the stars. Hα, Hβ, and the carbon line at λ 4267 are also found among the impurities. The presence of such a large number of Class B stellar lines among the impurities strengthens the conviction that the vacuum spark source closely approaches the condition of the early type stars.

SILICON LINES IN THE SPECTRUM OF RHO LEONIS

SPARK	INTENSITY	STAR	INTENSITY	Δλ
COINCIDENCES WITH SILICON LINES PREVIOUSLY KNOWN				
4088.88	6	4089.06	4½	−0.18
4116.15	6	4116.19	1	−0.04
4128.11	8	Lacking		
4130.96	10	Lacking		
4552.50	20	4552.63	5	−0.13
4567.66	16	4567.79	3	−0.13
4574.66	12	4574.74	2	−0.08
4813.28	3	4813.6	s	−0.3
4819.57	4	4819.2	½	+0.4
4828.84	6	Lacking		
COINCIDENCES WITH NEW SILICON LINES				
4304.15	0	4304.0	1	+0.15
4372.35	1	4371.9	½	+0.4
4638.36	1	4638.60	1	−0.24
4665.76	1	4665.6	s	+0.2
4709.20	1	4709.4	s	−0.2
4800.43	1	4800.1	s	+0.3
4837.97	1	4837.8	½	+0.2

[2]*Publications Detroit Observatory*, Vol. I, p. 120, 1915.
[3]*Publications Dominion Observatory*, Vol. V, p. 5, 1920.

In addition to the seven coincidences between new silicon lines and absorption lines of Rho Leonis, ten have been found with other unidentified absorption lines of Class B stars at wavelengths 3230.43, 3779.47, 4141.04, 4494.02, 4598.21, 4619.60, 5219.05, 5448.46, 5639.13, and 5796.71. It is quite probable that many of these stellar lines are due to silicon absorption.

Among coincidences noted between previously known silicon lines and stellar absorption lines, not identified by the observers, λ 3806.60, the strongest silicon vacuum spark line in this region, corresponds to λ 3806.4, observed by Dr. Kohl[4] in γ Orionis, the only unidentified line measured by him in the ultra violet. The line at λ 3790.9, given by Professor Pickering[5], corresponds to λ 3791.13 in the spark. The absorption line λ 4198.34, found by Professor Curtiss[6], in β Lyræ, agrees closely with λ 4198.25 of the spark.

It was not our original intention to include a study of coincidences between the silicon lines and stellar emission lines. A few remarkable cases, however, seem worthy of mention in this connection.

Three previously known silicon lines, λ 3853, λ 3856, and λ 3862, which show some disagreement in wave-length in the spark, are represented in the spectrum of β Lyræ, a Class Bp spectroscopic binary, by three bright lines, λ 3853.61, λ 3856.45, and λ 3862.55, measured by Professor Curtiss[6]. Our wave-lengths of these lines are as follows: λ 3853.01, λ 3856.09, and λ 3862.51. Although there is a greater discrepancy in two of these lines than we have admitted in the case of absorption lines, the anomalous behavior of the radiation both in the spark and in the star gives strong evidence in favor of the identification. Two new silicon lines, λ 4657.20 and λ 5185.64, may be represented by emission lines in γ Cassiopeiæ[7]; and others appear suspicious.

A remarkable set of coincidences has been noted between the silicon spark lines and the radiations of the Wolf-Rayet stars, γ Velorum and H. P.

[4]*Astronomische Mitteilungen der Sternwarte zu Göttingen*, XVI, p. 23, 1913.
[5]*Harvard Observatory Annals*, Vol. XXVIII, p. 235, 1897.
[6]*Publications Allegheny Observatory*, Vol. II, p. 87, 1911.
[7]*Publications Detroit Observatory*, Vol. II, p. 13, 1916.

1311, as given by Professor Pickering[8]. Between λ 3890 and λ 5800, there are at least eighteen coincidences between measured lines, including both emission and absorption, and measured edges of lines.

The number of coincidences between the new silicon lines and the absorption lines of Class B stars, and between the silicon spark lines and the emission lines of early type stars, seems to indicate that the vacuum spark source closely resembles the condition of these stars and that silicon plays a more important part in stellar radiation than has usually been attributed to it.

[8] *Harvard Observatory Annals*, Vol. XXVIII, pp. 244–248, 1897.

University of Michigan, December, 1922.

THE SPECTRUM AND RADIAL VELOCITY OF COMET *f* 1913 (DELAVAN)

By RALPH H. CURTISS and DEAN B. McLAUGHLIN

Spectrograms of Comet *f* 1913 (Delavan) were obtained on the dates, 1914, September 21, 25, 28, 29, and 30, with the single-prism spectrograph attached to the thirty-seven and one-half inch reflector of the Detroit Observatory. At that time the comet, at a heliocentric distance of 1.2 astronomical units, was approaching perihelion. Its geocentric distance was about 1.6 astronomical units, its closest approach to the earth. It passed perihelion 1.1 units from the sun, on October 26. Though the period chosen for these observations was the most favorable for this comet, its position was unusually unfavorable as it disappeared below the northern horizon for some time about midnight and at best could be observed only at low altitudes, early in the evening and before dawn.

The journal of observations is copied in its salient features into Table 1. It was noted in the observing book in connection with the first and second spectrograms that the comet's nucleus was sharp, indeed little if any larger than a star image; and this condition continued through to the last plate. During each exposure this sharp nucleus was held at and near the center of the slit; and in order that a record of the fainter parts of the head might be obtained a long slit was used. The lengths of the slit in seconds of arc are given in the column under S. To secure negatives of measurable density it was necessary to employ a relatively wide slit. Needless to say, though the exposures were all carried into the dawn, no risk was run of superposing any sky spectrum on the plates. For use as a velocity standard the last two spectrograms of Table 1 were made of the sky, employing a wide slit as for the comet spectrograms and a long slit for plate 3034 to provide for the determination of the large curvature correction peculiar to the comet plates. In all cases the comparison spectrum was that of the titanium spark.

TABLE 1
JOURNAL OF OBSERVATIONS

PLATE NO.	DATE 1914	EXPOSURE C. S. T.	EXPOSURE TOTAL	OBSERVER	S	REMARKS
		h m h m	m		″	
2998	Sept. 21	15 36 to 16 28	52	Curtiss	14	Sharp nucleus.
3004	25	14 23 to 16 28	125	Curtiss	34	Nucleus sharp with structure in head extending almost due east from nucleus.
3007	28	7 15 to 8 10				
		14 40 to 16 40	175	Curtiss		Smoky sky.
3008	29	13 52 to 16 44	172	Mellor	46	
3009	30	7 00 to 8 10				
		14 00 to 16 45	235	Curtiss	46	Clear horizon.
		SKY PLATES				
3032	Oct. 22	23 40	3[a]	Curtiss		
3034	23	0 08		Curtiss		Long comparison lines.

PLATE P. THE SPECTRUM OF COMET *f* 1913 (DELAVAN)
WITH TITANIUM COMPARISON EXPOSED 3 HR. 55 MIN.
1914, SEPTEMBER 30

All of the comet plates registered reflected solar spectrum and cometary emission bands. On each of the comet plates except 3007 comet bands could be measured for wave-length determination and on plates 3004, 3008, and 3009 enough Fraunhofer lines could be measured for good radial velocity determinations. These measures were carried out independently by the writers with results that are given and discussed below.

The radial velocities of the comet with reference to the observer from measures of features of the reflected solar spectrum on three dates, together with probable errors and comparisons with the computed radial velocity of the comet are found in Table 2. The columns in order from the left contain the plate number, the date, the velocities by each observer followed by probable errors and the number of features measured, the mean velocity for the two observers, the computed radial velocity of the comet, and the difference between the observed and computed velocities.

a lower power for both comet and sky plates which made it possible to measure many more features with undiminished accuracy. Notably measurable were a number of maxima in the continuous spectrum of the comet and of the sky. The greater number of features measured by Mr. Curtiss is thus explained and his smaller probable errors in a degree accounted for. The application of higher power by Mr. McLaughlin, though it leads to greater probable errors based on agreement of lines, strengthens the final results by introducing variety of method. The mean observed velocity in Table 2 is an average of the weighted and direct means of the velocities in columns three and six. This value was adopted in preference to the weighted mean in order to permit the personal equation and differing methods of each measurer to influence the final result in more nearly the same degree. The computed velocity of the comet includes the radial velocities of the comet with reference to the sun and the earth, obtained by numerical

TABLE 2

RADIAL VELOCITIES OF COMET 1913 *f* (DELAVAN)

PLATE NO.	DATE	VELOCITIES								
		CURTISS			MCLAUGHLIN			MEAN	COMP.	O−C
	G.M.T., 1914	km	p.e.	n	km	p.e.	n	km	km	km
3004	Sept. 25.89	−16.8	±3.3	30	−17.5	±5.0	12, 23	−17.1	−18.5	+1.4
3008	29.89	−12.4	2.4	36, 52	−13.8	4.3	17, 15	−12.9	−13.8	+0.9
3009	30.75	−12.5	2.1	62	−15.4	3.0	31, 28	−13.7	−13.0	−0.7

In four cases the observed velocities, in columns three and six of Table 2, are means of two complete measures. This is indicated by giving in columns five and eight the number of features entering into each such duplicated observation. Mr. McLaughlin measured each of the plates twice, with an interval of several months elapsing between repeated determinations. Nearly all of his measures were made with relatively high power with which only the stronger features could be measured. Mr. Curtiss subsequently adopted

differentiation, and the small component due to the earth's rotation.

Our results indicate that in a comet only moderately bright accurate radial velocities can be obtained from the reflected solar spectrum. The practicability of Moulton's method[1] for the determination of the elements of a comet's orbit from observed positions and radial velocities is thus brought out. It will be remembered that

[1] *Astrophysical Journal*, Vol. X, p. 14, 1899.

Albrecht[2] secured velocities considered reliable within two or three kilometers from the D emission lines in Comet *a* 1910, and Wright[3] a radial velocity from three Fraunhofer lines in Comet *c* 1911. A comparison of velocities determined from bright and dark lines in the same comet would be of interest.

The good agreement between observed and computed velocities of Comet *f* 1913 indicates that the motion of the particles in the comet reflecting the solar spectrum was very small in the line of sight relative to the nucleus.

In the study of the spectral features due to the comet's inherent radiation every emission maximum which gave promise of being a line or band was measured on our spectrograms. In general such maxima belonged to two classes, those which extended well over the entire length of the slit and those which reached little if any beyond the uncertain edge of the continuous spectrum. Most if not all of the former were due to the comet's inherent light. Many of the latter were probably maxima between absorption regions in the reflected solar spectrum of the nuclear region of the comet.

In Table 3, we give the data with reference to the emission features measured by us which are in most cases very probably cometary and which are in many cases identified with lines and bands in the spectrum of carbon and cyanogen. The several wave-lengths measured by each observer on four plates occupy the first eight columns. The means of these measures for each feature with the average intensity in this spectrum and number of measures follow in columns 9, 10, and 11. The results of the measures, apparently of the same features by Campbell and assistants in Comet *d* 1907[4], are found in column 12 and by Wright in Comet *c* 1911[5] in column 13, with wave-lengths by Kayser and Runge[6] in column 14. In the last column the notes include a brief description of the features measured, in which C denotes the center of a band, E the edge of greater wave-length, L long, S short, and W wide. The notes include also a statement of the identity of the feature measured when information is available.

The data in Table 3 leave no doubt that the fourth and fifth bands of the arc spectrum of carbon and the second and third bands of cyanogen occur in the comet's spectrum. No other identifications are made. Six bands with centers at 3880.5, 4052.7, 4686.4, 4697.0, 4715.1, and 4736.1 stand out strongly in the spectrum. The band at 4052.7 extends but little if any beyond the normal limits of the continuous spectrum, which however is extremely faint in this region on our spectrograms. It is a nuclear line. The other prominent bands are long, diminishing in brightness with increasing distance from the nucleus but not disproportionately strong when crossing the continuous spectrum. They are essentially lines of the coma, a statement especially true of the observed components of the third cyanogen band, though there appears to be a decided strengthening of the band at 3880 in the nuclear region on plate 3008. A striking feature, visible on Plate P, is the reversed curvature of the edge of greater wave-length of the cyanogen band at 3880. Similar irregularities are observed in other like features. Possibly if not photographic effects they are due to variations in the relative intensities of the various lines in these bands in different parts of the comet's head. Probably they are not Doppler effects.

Some changes of intensity some of which may have been due to increases in slit width were noted in the emission bands from night to night. Generally speaking these bands appeared to decline in brightness though in no pronounced degree from the beginning to the end of the series of plates, both absolutely and in comparison with the continuous spectrum. Thus the band with edge at 3871.8 was strongest on plate 3004, one of the weaker but earlier spectrograms. In this connection it will be noted in Table 3 that the measured edge of greater wave-length of all or nearly all of the prominent bands generally decreases in wave-length from the beginning to the end of the series. This change, possibly due to declining intensity of only the lines at the edges, is probably connected with a declining intensity of the bands, increasing slit-width, or both. No great alterations were observed in the relative

[2] *Lick Observatory Bulletins*, Vol. V, p. 183, 1910.

[3] *Lick Observatory Bulletins*, Vol. VII, p. 8, 1912.

[4] *Lick Observatory Bulletins*, Vol. V, p. 31, 1908.

[5] *Loc. cit.*

[6] *Anhang zu Abhandlungen K. Akad. Wiss., Berlin*, 1889.

intensities of the two parts of the long bands on either side of the nuclear spectrum, but in the fourth carbon band the east extensions appeared in general the stronger on September 25, and the west extensions on September 29 and 30. The structure noted in the head on September 25 possibly helps to account for this appearance.

In addition to the spectral features included in Table 3, many more or less narrow emission maxima were measured, though not identified. They appear to extend beyond the neighboring continuous spectrum probably because they are strong enough to be visible farther out on the vanishing edge of the nuclear light, and hence they appeal to the measurer as possible cometary bands. Bright regions of this character have been measured by Mr. Curtiss and verified by Mr. McLaughlin at 4245.8, 4252.6, 4257.7, 4264.3, 4274.5, 4278.0, 4316.1, 4349.2, 4397.5, 4402.9, 4412.1, 4413.1, 4419.4, 4429.1, 4438.9, 4453.0, 4464.0, 4477.0, 4485.5, 4569.7, 4578.7, 4588.5, 4643.2, 4660.7, 4663.0, 4705.7, 4759.8, 4866.2, and 4928.2. All of these twenty-nine lines coincide closely with emission maxima in the spectrum of the sky and with few exceptions in Comet *f* 1913 are almost certainly features of the reflected solar spectrum. In addition Mr. Curtiss has measured the following emission maxima in the spectrum of this comet, which are mentioned here with no positive suggestion of cometary origin, 4132.1, 4162.3, 4232.8, 4236.8, 4270.9, 4497.3, and 4747.8. Of the above lines the following have been used by Mr. Curtiss with satisfactory results in differential radial velocity determinations based on sky spectra, 4252.6, 4257.7, 4274.5, 4278.0, 4397.5, 4402.9, 4412.1, 4413.1, 4419.4, 4438.9, 4485.5, 4588.5, 4643.2, 4663.0, and 4866.2. These features are confined to the region from 4130 to 4928 because the reflected solar spectrum was not measurable beyond these limits on our spectrograms.

Of the lines in the preceding paragraph thought to be of solar origin in Comet *f* 1913, the following are closely identical in position with bands measured in the same region of the spectrum of Comet *d* 1907[7] but, with one exception, not in Comet *b* 1893[8], Comet *b* 1894[9], or in Comet *a* 1899[10], 4278.0, 4316.1, 4349.2. 4397.5, 4402.9, 4412.1, 4419.4, 4438.9, 4453.0, 4485.5, 4588.5, and 4705.7. In addition the following emission maxima or bands measured in the spectrum of Comet *d* 1907 have close solar counterparts or are involved in solar maxima, 4292, 4297, 4304, 4335, 4537, 4720, and 4725. A few lines with assigned identifications measured by one observer on one spectrogram of Comet *d* 1907 correspond closely to solar spectrum maxima at 4166, 4169, 4180, and 4185. Two of these are found in Table 3 of the present paper together with a possible cometary band at 4193.6, measured also in Comet *d* 1907 on one plate, apparently involved with a well defined maximum in the solar spectrum. Of the twenty-four bright maxima or bands referred to here as measured in Comet *d* 1907, eighteen were measured on only one plate and in each case by one of the three observers who studied that plate. In connection with the sixty-one published bright lines measured in Comet *d* 1907, it was noted at the time that some were possibly unreliable, for the reason that they were involved with the comet's continuous and dark line spectrum as a background, making it impossible always to determine whether a certain appearance was due to a bright line or to continuous spectrum between dark lines. Such lines, with the rest, were placed on record for future comparison.

In Comet *c* 1911[11] the spectrograms were compared with spectra of the sky prepared with the same instrument, in order to eliminate any bright maxima considered to be doubtful cases. In this comet there are apparently seven measured emission features mentioned above because of close association with or involvement in maxima of the solar spectrum and not clearly identified with known lines. They are of wave-lengths, 4265, 4292.2, 4297.4, 4303.8, 4334.8, 4349, and 4660. Possibly 4723 should be included with them, for this line together with 4720 and 4725 in Comet *d* 1907, appears to be involved in a wide emission maximum of the solar spectrum. Five of these lines in Comet *c* 1911 were measured in Comet *d* 1907 and three in Comet *f* 1913.

[7] *Loc. cit.*

[8] *Astronomy and Astrophysics*, Vol. XII, p. 652, 1893.

[9] *Astronomical Journal*, Vol. XIV, p. 111, 1894.

[10] *Astrophysical Journal*, Vol. X, p. 174, 1899.

[11] *Loc. cit.*

TABLE 3

WAVE LENGTHS OF EMISSION FEATURES, COMET *f* 1913

PLATE 2998		PLATE 3004		PLATE 3008		PLATE 3009		MEAN	INT.	NO.
CURTISS	MC-LAUGHLIN	CURTISS	MC-LAUGHLIN	CURTISS	MC-LAUGHLIN	CURTISS	MC-LAUGHLIN			
		3866.4						3866.4	5	1
						3869.0		3869.0		1
		3873.7				3870.0		3871.8		2
3881.5	3881.0	3879.6		3880.2		3880.0		3880.5	10	5
3882.5	3881.8	3881.8	3881.0	3881.8	3881.1	3881.2	3881.1	3881.5		8
						4040.0		4040.0	2	1
		4044.2		4043.7		4044.6		4044.2	1	3
4053.0	4052.4	4052.8	4053.0	4052.4	4052.4	4052.6	4052.6	4052.7	5	8
		4074.6				4075.1		4074.9	3	2
						4170.8		4170.8	3	1
		4180.6						4180.6	3	1
						4193.6		4193.6	3	1
4213.3		4214.0				4213.0		4213.4	3	3
4214.0		4214.7				4215.0		4214.6		3
		4364.4				4364.6		4364.5	3	2
		4365.7				4365.1		4365.4		2
		4371.8				4372.2		4372.0	1	2
						4372.8		4372.8		1
		4379.7		4379.4		4379.8		4379.6	4	3
		4381.0				4381.1		4381.1		2
			4672.8		4671.9		4671.2	4672.0	1	3
						4678.8		4678.8	2	1
			4679.0		4678.6	4680.0	4677.9	4678.9		4
4686.5				4686.8		4685.8		4686.4	4	3
4688.5	4687.5		4686.3	4687.2	4687.7	4686.8	4686.1	4687.2		7
4698.4		4697.0		4696.0		4696.8		4697.0	5	4
4700.7	4699.0	4698.2	4698.0	4698.3	4698.5	4698.2	4698.2	4698.6		8
4716.8		4715.0		4714.0		4714.6		4715.1	7	4
4717.9	4716.5	4717.8	4716.0	4716.5	4716.2	4715.4	4715.8	4716.5		8
4736.5		4735.5		4736.2		4736.2		4736.1	6	4
4737.6	4736.6	4737.9	4737.4	4737.3	4737.5	4737.3	4737.0	4737.3		8
		4760.2						4760.2	1	1

TABLE 3

WAVE LENGTHS OF EMISSION FEATURES — CONTINUED

COMET *d* 1907	COMET *c* 1911	KAYSER AND RUNGE	NOTES
			C L Strong line 3d Cy
	3868.8		C L Maximum near 2d edge 3d Cy
3870.5		3871.54	E L 2d edge 3d Cy
3879.7	3881.2	3879.62	C L Strong band 3d Cy
3882.3		3883.55	E L 1st edge 3d Cy
4039.0	4040.0		C S
4042.8	4043.0		C S
4052.9	(4051.5)	4053.35	C S Narrow strong line 2d Cy
4074.0	4074.6	4073.69	C S W Strong line 2d Cy
4169.		4167.77	E L? 4th edge 2d Cy
4180.		4180.98	E L 3d edge 2d Cy
4193.2		4193.03	C S Strong line 2d Cy
	4215.0		C S? Maximum near 1st edge 2d Cy
4214.6		4216.12	E S? 1st edge 2d Cy
	4364.5		C L Maximum near 3d edge 5th C
4364.5		4365.01	E L 3d edge 5th C
	4371.3		C S? Maximum near 2d edge 5th C
4371.3		4371.31	E S? 2d edge 5th C
	4381.		C L Maximum near 1st edge 5th C
4380.7		4381.93	E L 1st edge 5th C
4670.7	4672.		E L
4677.6	4678.0		C L Maximum near 5th edge 4th C
			E L 5th edge 4th C
	4684.2		C L Maximum near 4th edge 4th C
4684.3		4684.94	E L 4th edge 4th C
	4696.8		C L Maximum near 3d edge 4th C
4697.0		4697.57	E L 3d edge 4th C
	4714.6		C L Maximum near 2d edge 4th C
4714.9		4715.31	E L 2d edge 4th C
	4736.4		C L Maximum near 1st edge 4th C
4736.6		4737.18	E L 1st edge 4th C
			E L

It is not our purpose to question the non-solar origin of these unidentified nuclear lines in any except Comet *f* 1913. Each comet is a law unto itself so far as spectra are concerned and a cometary line may be registered in or near solar emission maxima in one comet and be unrecognizable or absent in another perhaps similar in other respects. It has been of importance to place on record these bright features as measured in the nuclear spectrum of different comets for they should be kept under observation in the future. If they are bright lines or emission bands in any given comet they should be displaced with reference to the reflected solar spectrum by an amount of the same order as that due to the radial velocity of the comet with reference to the sun. Thus suggested identifications could be tested in favorable cases. If many of these nuclear emission maxima are features of the comet's inherent light they must complicate the determination of radial velocities from the Fraunhofer lines. Quite otherwise in Comet *f* 1913, a number of them as well as near by dark lines have been used successfully in radial velocity measures. If these unidentified bright maxima originate in the comet's nucleus or in the head they must influence our ideas with reference to conditions in comets not very close to the sun.

A good general idea of the spectrum of Comet *f* 1913 may be gained from the reproduction of plate 3009, of September 30, 1914 (see Plate P). The comparison spectrum of titanium is conspicuous above and below. The nuclear spectrum occupies the center, its width being partly due to unavoidable drifting of the image on the slit. It is essentially a reflected solar spectrum with a few visible bright bands superposed. Wave-lengths at the margin call attention to three conspicuous bands of which 3880 of cyanogen and 4737 with its neighboring bands of carbon are long and 4053 probably of cyanogen is short and nuclear. The reversed curvature of the right hand edge of the former is notable. It is probable as observed in several other comets that the maximum of the continuous spectrum is displaced toward the red as compared with the sky spectrum. In the continuous spectrum a number of maxima resembling emission lines may be seen especially in moderately weak regions. Nearly all of these are found in the solar spectrum and are probably not features of the comet's inherent radiation.

Our study of the spectrum of Comet *f* 1913 has yielded three good radial velocities of the nucleus of this object in satisfactory accordance with the theoretical motion. It has also resulted in the determination of many wave-lengths of possible emission features. Discussion of these results together with some determined from other comets and from sky spectrograms lead to the following conclusions. Useful radial velocities can be obtained from the reflected solar spectrum of a comet only moderately bright. The motion of the particles in Comet *f* 1913 reflecting the solar spectrum was not large in the line of sight relative to the nucleus. Bands of carbon and cyanogen were emitted by the head and nucleus of the comet. Changes occurred in the appearance of some of these bands. Many features in the spectrum of the nucleus resembling bright lines were probably identical with maxima of radiation in the spectrum of the sun.

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